Stephen P. Markle, P.E.

Lieutenant Commander, U.S. Navy

Deputy Director, Environmental Programs Division

Naval Sea Systems Command

Mr. Sean E. Gill

Senior Engineer

GEO-CENTERS, Inc.

Mr. Peter S. McGraw, P.E.

Acting Solid Waste Branch Head

Naval Surface Warfare Center, Carderock Division

ENGINEERING THE ENVIRONMENTALLY SOUND WARSHIP FOR THE 21st CENTURY

ABSTRACT

The past twenty-five years has been marked by the introduction of marine environmental regulations that have had a profound effect on how ships are designed, built and operated. Ships being designed and built today must accommodate not only current regulations but anticipate those enacted over their thirty to fifty year life cycles. U.S. Chief of Naval Operations, Office of Environmental, Safety and Health (CNO N45) has articulated a vision for the Environmentally Sound Warship of the 21st Century. This vision incorporates the “Sense of Congress” for a naval ship designed to operate in full compliance with environmental regulations worldwide. The task of the Navy

Engineering Team is to translate this vision into reality, a ship capable of prevailing in time of war, and able to conduct operations in all areas of the globe, unencumbered by special procedures for environmental compliance. The keys to this warship design are: the early integration of environmentally sound principal's, materials and processes into the ship acquisition process; minimization of both hazardous materials and generation of post shipboard consumer waste during operation; adaptation of integrated systems to reduce the volume of wastes and enhance processing efficiency; reduced manpower requirements, and crew indoctrination in environmental protection.

INTRODUCTION

Today the U.S. Navy is operating throughout the world in a climate of ever changing, more restrictive, environmental regulations. Conducting peacetime Naval Operations around the globe is a complex and demanding exercise in planning and execution. Added to the traditional areas of tactics, logistics, communications, administration and safety are those of compliance with a myriad of international treaties and host nation regulations not the least of which are those involving protection of the environment.

To meet these challenges and facilitate continued unrestricted naval operations, the Navy has adopted a four pronged leadership approach for afloat environmental compliance:

- Change in operational procedures;
- Education of all personnel;
- Source reduction and pollution prevention measures; and
- Installation of shipboard pollution control equipment.

OPNAV Instruction 5090.1 Series, "Environmental and Natural Resources Program Manual", Chapter 19 translates the myriad of international and national environmental laws and regulations into Navy requirements for Afloat Environmental Protection. Specific guidance converts the legislative and regulatory requirements into distinct actions that ships must accomplish when managing: Solid Waste, Wastewater (Sewage, Graywater, and Oily), Ballast Water, Ozone Depleting Substances (Chlorofluorocarbons (CFC's) and Halon), and Hazardous Materials (HAZMAT). The most recent change includes a new requirement for each ship to have a designated Afloat Environmental Protection Coordinator (AEPC). The AEPC provides the command organizational support in executing operational aspects of mission performance. It is the Navy's goal to ensure that the Fleet carries out its military mission while meeting all applicable national and international environmental regulations. Conduct of naval operations is compatible with afloat environmental protection requirements provided the ship is outfitted with necessary equipment, procedures are in place, and the crew indoctrinated in what is required.

The Navy of tomorrow is being designed and built today to bring to reality the CNO N45 vision for the Environmentally Sound Warship of the 21st Century (ESW 21). Simply stated, this ship will have the following attributes:

- Compliance with all applicable environmental laws and regulations;
- Operate with no significant environmental impacts;
- Wastes treated or destroyed onboard to the maximum extent practicable;
- No inappropriate dependence on shore facilities for waste offload and disposal;
- Minimal logistical costs for waste management; and
- Minimal use of Hazardous Materials throughout the ship's life cycle (Cradle to Grave).

These common sense goals are being included in new ship acquisition program documents such as Operational Requirements Documents (ORD), and whole ship Performance Specifications. Top level Department of Defense (DoD) acquisition guidance contained in DoD Regulation 5000-2.R, section 4.3.7, establishes five mandatory Environmental, Safety and Health program elements. Commonly referred to as the "Five Pillars," policy and procedural requirements are given as "All programs, regardless of acquisition category, shall comply with Environmental, Safety and Health…and be conducted in accordance with applicable federal, state, interstate and local environmental laws and regulations, Executive Orders, treaties and agreements. The Program Manager shall ensure that the system can be tested, operated and repaired in compliance with environmental regulations…" (DoD Regulation 5000.2-R). The Five Pillars are:

- Compliance with the *National Environmental Policy Act* which requires analyzing proposed actions for effects on the environment;
- *Compliance* with all current and foreseeable environmental regulations;
- Identify and evaluate *System Safety and Health Hazards* by defining risk levels and developing a program that manages the probability and severity of all hazards associated with system development, use and disposal;
- Establish a *Hazardous Material Management Program* that ensures appropriate consideration is given to eliminating and reducing the use of hazardous materials in processes and products rather than simply managing pollution created; and
- In designing, manufacturing, testing, operating, maintaining, transporting, and disposing of systems, all forms of *Pollution shall be Prevented* or reduced at the source whenever feasible.

The intent is to ensure systems are compliant with the law, safe for operation and maintenance, and waste streams and hazardous materials are minimized.

The challenge for the ship design acquisition team made up of government and industry naval architects, engineers, ship builders, and program managers is to transform these attributes into physical existence. This goal of an "environmentally sound warship" will allow the Navy to operate and comply worldwide with minimal imposition by regulatory authorities, without the dependence on shore facilities, without unreasonable costs and degradation of shipboard quality of life. In this sense, the ability to comply with environmental protection requirements becomes an enabler for continued Unrestricted Naval Operations.

BACKGROUND

U.S. Navy Warships are unique in the marine environment. They are instruments of public policy, operated to conduct sustained naval operations and prevail in time of conflict. Often deployed to the far corners of the world for extended periods of time, these ships operate in a hostile environment at the end of a long logistical support chain.

The Navy is in the process of backfitting all ships in the Fleet with first generation technologies and procedures for managing sewage and wastewater, solid waste, oily waste, and excess hazardous materials.

The application of successful ashore environmental protection equipment to warships is complicated by the unique characteristics of naval warships. These ships are designed for extended periods at sea in a variety of sea states, weather and climate conditions. Surface warship designs are typically volume limited, weapon systems being designed in the smallest package to conserve energy requirements and minimize visual and electronic detection. The majority of equipment built for ashore or commercial marine application is not designed for the unique naval ship-operating environment. The primary differences include: space and weight limitations, shock and vibration requirements, electromagnetic interference (EMI) hardening, ship motions in six degrees {Surge (longitudinal), Sway (lateral), Heave (vertical), Pitch, Roll and Yaw}, and most importantly the average skill level of the typical naval operator.

Comparisons are often made between commercial ships and naval warships regarding adoption of commercial marine technologies for warship use. In most cases, differences in ship operating profiles (frequency of port calls, area of operations, logistic support constraints, etc.) crew size and training/certification levels of the crew make this transition difficult. For these reasons, direct comparison is not appropriate and misleading. Commercial cruise ships make frequent port calls allowing opportunities for offload of solid waste, ships engaged in commercial shipping are manned at minimal levels resulting in minimal waste generation, and most dedicated operators and maintainers of commercial ships are licensed via appropriate regulating body. Naval ships make infrequent port calls over six month deployments, have a much greater crew density, and have a greater number of people (frequently with high turnover rates) maintaining and operating equipment, thus compounding the training and certification challenge. However, commercial industry has much to offer and careful consideration must be given to apply Commercial Off the Shelf (COTS) technologies in warship design where it makes sense. The challenge facing the warship designer in adapting COTS solutions is summarized in Figure 1. Warships truly are different than all other ships.

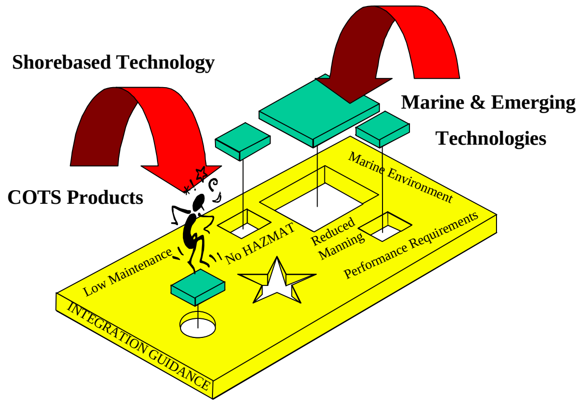

Figure 1. Marine Technology Filter Concept

The challenges facing today's sailors span the full range of issues. Figure 2 provides a summary of results obtained from the 1997 Fleet Wide Environmental Questionnaire (FWEQ) conducted by visiting seventeen ships in San Diego, California and Norfolk, Virginia. This survey found that the most challenging environmental issues facing the Fleet today are management of: Hazardous Material (HAZMAT), Oily Waste, Sewage and Solid Waste. Training concerns underlay each of the survey response areas (NAVSEA June 1997). ESW 21 must incorporate both systems and an associated training philosophy for thorough indoctrination of crewmembers. Institutionalization of the AEPC, and use of this position to advise the Commanding Officer and focus shipwide attention on environmental protection are key to achieving the ESW 21.

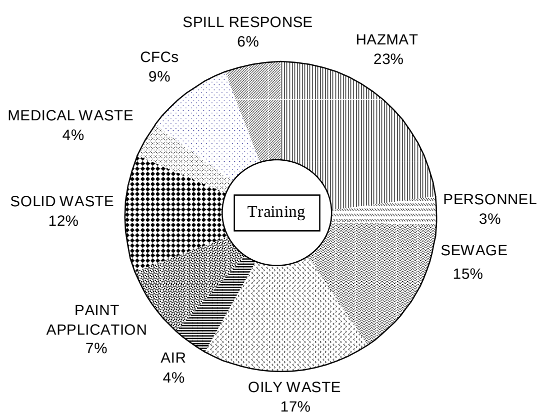

Figure 2. Fleet Wide Environmental Questionnaire Summary

Current Navy afloat environmental protection (AEP) technologies have been designed and installed to enable compliance with existing legal requirements. These first generation, stand-alone pollution control systems manage the various waste streams while at sea and facilitate disposal ashore. In fiscal year 1995, the Navy expended roughly $67.5M for disposal of these wastes ashore (NAVSEA November 1997). Figure 3 breaks down these costs by individual waste stream. Systems used today direct the waste streams but do little to reduce it. To be considered, future systems must both direct and minimize it, thereby reducing ship total ownership cost (direct life cycle plus indirect shore infrastructure support costs).

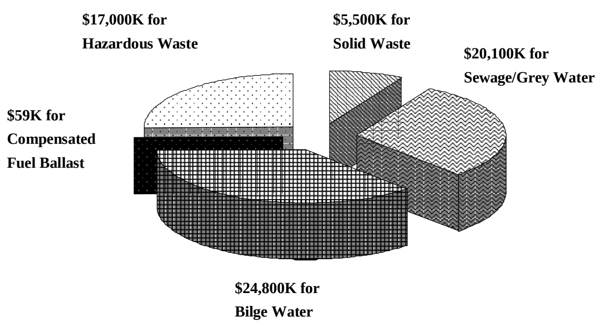

Figure 3. Cost of Environmental Compliance Using Current Technology (FY95)

Future ship designs must incorporate technologies that reduce manpower requirements, thereby allowing smaller allocation for services that support the crew. Insertion of appropriate environmental protection technologies together with manning goals into the traditional design spiral at the earliest opportunity is essential for adequate integration in the ship design. ESW 21 integrated waste management systems must be designed not only for compliance with today's regulations but with those anticipated for the future. The systems engineering process must begin with required performance characteristics and identification of waste stream parameters before system designs are finalized, as shown in the phased ship design concept of Figure 4.

Incorporation and implementation of a sound environmental protection strategy early in the ship acquisition process has two principal advantages, the reduction of overall program risk and reduction in Total Ownership Cost (TOC). Reduction in TOC stems from up-front cost savings from pollution prevention measures during design and construction, analysis of the expected regulatory regime under which the ship will operate and selection of the least life cycle cost pollution control devices and their incorporation into the design early, and by conducting early National Environmental Policy Act (NEPA) studies and analysis thereby preventing costly program delays and changes to the acquisition strategy.

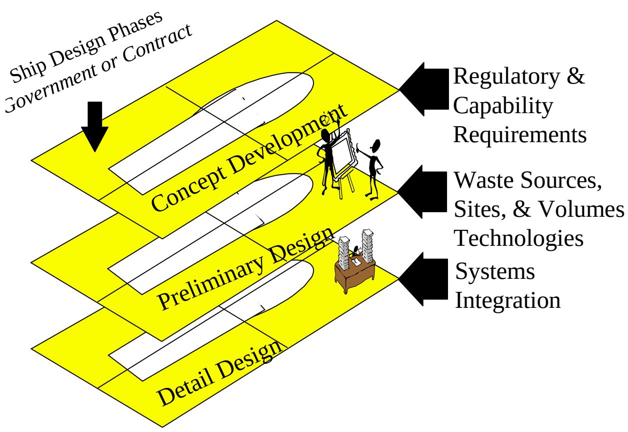

Figure 4. Design Guidance Overview Model

REQUIREMENTS

Unlike most naval mission requirements, which are warfighting based, AEP derives from international, national, state and local law. The International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) has five Annexes that regulate discharge of Oil, Hazardous Material, Sewage and Solid Waste on the high seas. Two new Annexes are under development for Air Pollution Control and Ballast Water Management for non-indigenous species control. Once ratified by the U.S. Congress, these Annexes become federal law and may apply to the Navy. Table 1 provides a list of these Annexes and their applicability to the U.S. Navy.

Table 1: MARPOL 73/78 Annex Status

Annex	Area	Status
I	Oil Pollution	Ratified/Applicable
II	Noxious Liquids	Ratified/Applicable
III	Hazardous Material	Ratified/Applicable
IV	Sewage	Not Ratified/Not Applicable
V	Garbage	Ratified/Applicable
VI	Air Pollution	Not Ratified/Not Applicable
VII	Ballast Water Exchange	Under Development

At the Federal level, there are three primary categories of concern: statutes (laws), regulations and Executive Orders. The major Federal Statutes affecting U.S. Navy operations are the Federal Water Pollution Control Act (Clean Water Act (CWA)) {HAZMAT, sewage and wastewater}, Clean Air Act (CAA), Resource Conservation and Recovery Act (RCRA) {HAZMAT}, Ocean Dumping Act, Act to Prevent Pollution from Ships (APPS) {solid and oily waste}, National Environmental Policy Act (NEPA), and the Marine Mammal Protection Act. The Code of Federal Regulations (CFR) contains general and permanent regulations of executive agencies and departments of the Federal government. The two most relevant are Title 33 CFR – Navigation and Navigable Waters, and Title 40 CFR – Protection of Environment. State and local regulations vary widely between locations. The challenge facing the ship designer is to consider the most restrictive scenario, anticipate changes within the expected operating area and design accordingly.

Solid Waste

In 1987, the U.S. Congress ratified Annex V to MARPOL 73/78 as the Marine Plastic Pollution Research and Control Act (MPPRCA) which amended APPS. Annex V established a worldwide prohibition on the discharge of plastic waste at sea, and established eight "Special Areas" where the discharge of other solid waste was deemed to be detrimental to the marine environment. These special areas are: Wider Caribbean Area, Mediterranean Sea, Black Sea, Persian Gulf, Red Sea, Baltic Sea, North Sea and the Antarctic Region (south of 60 degrees south latitude) and are shown in Figure 5. Currently, only the three latter "Special Areas" are in effect, the other areas will go into force following certification of adequate shore based solid waste management facilities. Approximately 50% of U.S. Navy deployed ships operate in these special areas.

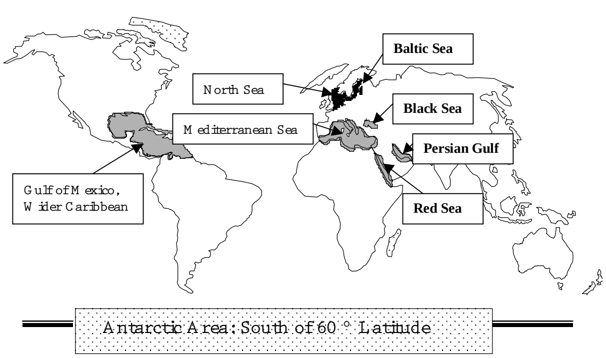

Figure 5. MARPOL 73/78 Annex V Special Areas

As originally ratified by Congress, public vessels were required to comply with the full discharge regulations for plastic waste and the “Special Area” restrictions of Annex V. The fiscal year 1994 National Defense Authorization Act (NDAA) validated Navy efforts of processing and onboard storage for plastic waste management and provided Milestones for completion by December 31, 1998, but directed the Navy to develop a plan by November 1996 for full compliance by all Navy ships. Congress further directed the Navy to include other Federal agencies and the public in preparing the plan. The Navy completed a detailed Environmental Impact Statement (EIS) on the effect of U.S. Navy proposed “Special Area” discharges in August 1996. The EIS evaluated various strategies from holding all solid waste aboard until able to discharge ashore/overboard or retrograde to Combat Logistic Force ships, impact on crew quality of life, adaptation of commercially available equipment (i.e. incinerators, bailers, compactors, pulpers, etc…), and analysis of the fate and effects of overboard discharge of pulped biodegradable material and shredded metal and glass into the “Special Areas” (U.S. Department of the Navy August 1996). This analysis showed that the pulper and shredder alternative would have no significant impact on the environment, considering the types and quantities of waste discharged by Navy ships. In addition, the Navy would use these pulpers and shredders worldwide, thereby eliminating floating debris and potential beach litter (U.S. Department of the Navy November 1996). The fiscal year 1997 NDAA provided congressional concurrence with the Navy discharge strategy and authorized fleet modernization plans, with an objective for completion of December 31, 2000.

Section 3.c of APPS (33 U.S.C. 1902 (c)) as amended by the 1997 NDAA provided the “Sense of Congress” that “it should be an objective of the Navy to achieve full compliance with Annex V to the Convention as part of the Navy's development of ships that are environmentally sound.” For this reason, future ship designs should incorporate technology capable of achieving zero discharge of solid waste within the Annex V Special Areas.

Oil Pollution Abatement

MARPOL 73/78 Annex I as ratified by APPS and the CWA regulate overboard discharge of oily waste. Annex I established four “Special Areas” where discharge of oil from ships in excess of 400 gross tons is prohibited, they are: Mediterranean Sea, Baltic Sea, Black Sea and the Antarctic Area. Annex I further limits the oil content of discharges too less than fifteen parts-per-million (ppm) in all other areas of the world. As ratified in APPS, Annex I requirements are invoked on warships to the maximum extent practicable without impairing operational capability. CWA prohibits the discharge of oil in harmful quantities within twelve nautical miles (nm) of the U.S. coast. U.S. Environmental Protection Agency (EPA) has interpreted harmful quantities as one that violates applicable water quality standards or causes a sheen on the water. As a matter of practice, fifteen-ppm is usually sufficient to cause a sheen. Future regulations for overboard discharge are expected to limit oil content to less than ten-ppm worldwide.

Sewage and Wastewater Control

MARPOL 73/78 Annex IV has not been ratified by the U.S., sewage and graywater discharge being subject only to CWA provisions. Currently, warships discharge untreated sewage when outside of three nm, hold all sewage when within three nm of land, and pump it ashore when in port to shore based treatment works. As a rule, most warships pump graywater (shower, sink and laundry drains) overboard when underway.

The NDAA of 1996 amended Section 312 of the CWA by providing for Uniform National Discharge Standards (UNDS) for vessels of the armed services. This legislation requires the Navy and EPA to establish Marine Pollution Control Device (MPCD) performance standards for vessel discharges, exclusive of sewage. MPCDs can take the form of management practices or technology. Selection of discharges for regulation was based upon seven criteria: Nature of the discharge; Environmental effects of the discharge; Practicability of using an MPCD; Operational impact of an MPCD on a vessel; Applicable United States law; Applicable international standards; and Costs of MPCD installation and use. When completed in 2003 these standards will apply to the U.S. Contiguous Zone (within twelve nautical miles of land) and be applicable in all U.S. territorial waters. Table 2 provides a listing of the UNDS discharges as listed in the Notice of Proposed Rule Making (EPA and DoD 1998). Future wastewater discharge requirements are expected to prohibit overboard discharge of untreated sewage within twelve nm of land, and the remaining wastewater discharges will be regulated via UNDS.

Table 2: UNDS Proposed Regulated Discharges

Aqueous Film Forming Foam
Catapult & Water Brake Tank and Post Launch Retraction Exhaust
Chain Locker Effluent
Clean Ballast
Compensated Fuel Ballast
Controllable Pitch Propeller Hydraulic Fluid
Deck Runoff
Dirty Ballast
Distillation and Reverse Osmosis Brine
Elevator Pit Effluent
Firemain Systems
Gas Turbine Water Wash
Graywater
Hull Coating Leachate
Motor Gasoline Compensating Discharge
Non-oily Machinery Wastewater
Photographic Laboratory Drains
Seawater Cooling Overboard Discharge
Seawater Piping Biofouling Prevention
Small Boat Engine Wet Exhaust
Sonar Dome Discharge
Submarine Bilgewater
Surface Vessel Bilgewater/Oil-Water Separator Discharge
Underwater Ship Husbandry
Welldeck Discharges

Hazardous Material

The CWA prohibits the discharge of harmful quantities of hazardous substances into or upon U.S. waters out to 200 nm. RCRA regulates generation, treatment, storage and disposal of hazardous waste. RCRA further provides that hazardous waste generated aboard public vessels is not subject to storage, manifest, inspection or record keeping requirements until the ship transfers such waste ashore or to another public vessel within the territorial waters of the U.S. (Solid Waste Disposal Act, Section 3022). Generally, designation of materials as "hazardous" has been the responsibility of the EPA. Hazardous materials typically are: ignitable, corrosive, reactive or toxic. Greater understanding of material properties and how they react with other compounds and the ambient environment in which they are used has resulted in an increasing number of substances being declared hazardous. This trend is expected to continue in the future, with management practices being required to mitigate harmful effects of designated materials. The Toxic Substances Control Act (TSCA) provides the EPA with the authority to ban or limit the manufacture, distribution and use of substances found to present an unreasonable risk. Examples of TSCA regulated materials are asbestos, lead and Polychlorinated Biphenyls (PCBs). Management of program risks due to unforeseen material classifications as hazardous presents a significant program challenge. This risk may be best mitigated by informed decision making on materials to be used, and attention given to those that are deemed to be, or potentially, hazardous. Navy policy prohibits overboard discharge of hazardous material, and promotes its minimization and substitution with environmentally preferable materials.

Air Emissions

Air emissions include engine exhaust, incinerator exhaust, volatile organic compounds released from solvents and coatings, refrigerants, and other gaseous substances. Diesel engine and marine incinerator emissions are covered under MARPOL 73/78 Annex VI, which has not yet been ratified by the U.S. CAA authorizes state and local governments to set standards for emissions of air pollutants to enable compliance with National Ambient Air Quality Standards (NAAQS). Currently warship propulsion plants and incinerators are unregulated with the exception of smoke opacity when in port. This is expected to change with ratification of Annex VI, and adoption of marine regulations by certain states in the near future. The Navy uses a considerable number of gas turbine and internal combustion (primarily diesel) engines for ship and aircraft propulsion, power generation, and a host of other services (e.g. fire fighting pumps). All of these engines produce air emissions depending on the engine type, application, fuel type, power level, operating time, etc. The primary pollutants produced in engine exhausts are oxides of nitrogen (NOx), oxides of sulfur (SOx), carbon dioxide, carbon monoxide, particulates, and hydrocarbons. Carbon dioxide is not really a pollutant but is considered a greenhouse gas and may contribute to global warming. Navy engine air emissions are not presently regulated and the Navy does not employ any treatment methods to reduce emissions (except to lower the temperature of certain exhausts for infra red suppression). This may change in the future when Annex VI to MARPOL is ratified and/or if implementing domestic legislation is passed. Annex VI requires that diesel engines (130 kW or larger) installed on new construction ships after January 1, 2000 or undergoing a major conversion after January 1, 2000 be able to meet certain NOx emission standards dependent on engine rpm. Annex VI also limits fuel sulfur content to 4.5 percent (1.5 percent in a SOx Emission Control Area) which will have no impact on Navy ships as their current fuel (NATO F-76) contains only one percent sulfur. EPA has initiated action to regulate marine diesel engines of 37 kW and larger when operating up to 200 nm from land (EPA November 1998). The National Security exemption excludes warships, but establishes an approach for future regulation. Gas turbine engine emissions are not presently regulated nor are they expected to be in the foreseeable future.

CFCs and Halons are two types of synthetic chemicals (considered in CAA as Class I Substances) that are essential to the operation of Navy ships as they are heavily relied on in air conditioning, refrigeration, and fire fighting systems. However, they have also been linked to the destruction of the Earth's protective stratospheric ozone layer resulting in their inclusion in a relatively recent category of compounds called Ozone Depleting Substances (ODSs). The 1990 amendments to the CAA ratified the provisions of the Montreal Protocol, a 1987 international agreement that took action to protect the stratospheric ozone layer. CAA Section 604 prohibits production of Class I substances after January 1, 2000, and in section 606 provided the Administrator of the EPA the authority to accelerate this schedule. On February 11, 1992, the U.S., responding to recent scientific findings, announced that the phase-out of the production of CFCs and Halons would be accelerated and that these substances would be phased out by December 31, 1995 (EPA 1993).

Table 3: ESW 21 Environmental Regulation Summary

Waste Stream		**Expected ESW 21 Requirements**
Liquid	Oil and Oily Waste	UNDS – To Be Determined {$\leq$ 10 ppm?}
	Sewage	No Discharge of Untreated within 12 nm of Land
	Graywater	UNDS – To Be Determined
	Ballast Water	UNDS – To Be Determined {Likely regulated dilution in open ocean?}
Solid	Food	No Discharge of Unpulped within 12 nm of Land
	Paper & Cardboard	No Discharge in Annex V Special Areas, No Discharge within 12 nm of Land
	Metal & Glass	No Discharge in Annex V Special Areas, No Discharge within 12 nm of Land
	Plastic	No Discharge
	Dunnage	No Discharge
	Hazardous	No Discharge
	Infectious Medical	No Discharge
Air	Engines	Engine Specific, Gas Turbines – None Anticipated
	Incinerator	Annex VI for Oxygen, Carbon Monoxide, Temperature, Ash and Opacity
	ODS	Prohibited Use
	VOC	Limited Use, Locality Specific

SHIP AND EQUIPMENT DESIGN CONSIDERATIONS

The key to the design of the ESW 21 is considering the environmental impact of the ship throughout its entire life, from cradle to grave. This requires the integration of environmentally sound principles throughout the ship's conception (planning/design), growth (construction), life (operations), retirement (decommissioning) and death (scrap/recycling). Processes that must be employed include minimization of hazardous materials and other waste streams; adaptation of integrated systems to efficiently manage what wastes are generated; incorporation of technologies to reduce manpower requirements; and indoctrination of the crew in the fundamental principles of environmental protection.

The mission, performance goals, and life span of a new ship design are found in program planning documents such as Operational Requirements Documents (ORD), and whole ship Performance Specifications. The preparation of these documents and specifications must integrate the environmental requirements, goals and strategies throughout. It is the job of the ship design team, made up of government and industry naval architects, engineers, ship builders, and program managers, to transform these attributes into physical existence. These documents provide the design team with the ship's intended mission and manning. The definition of the mission profile (operational area, days at sea, etc...) is critical to providing the environmentally sound ship design. The number of days at sea drives the balance between onboard storage/retrograde or processing of waste, while operational distance from shore dictates environmental regulation applicability. Tradeoff studies conducted to determine propulsion plant type, auxiliary equipment, weapons systems, aircraft, etc…, must consider the cost of compliance and risk associated with applicable environmental regulations of each alternative. Ship design, mission and operational profile determine its environmental impact.

The ship's mission and design determines its manning requirements. Manning is the major driver for the generation of waste. This is especially true for the generation of solid and liquid waste. As technology improves, manning numbers will decrease. It is expected that the next generation destroyer, DD 21, will only have a full crew complement of less than 100, while the current *Arleigh Burke* (DDG 51) Class has a crew of approximately 350. Similarly, it is expected that the new aircraft carrier, CVN 77, will carry fewer than 5,500 persons, while the *Nimitz*

(CVN 68) Class was designed for full manning of 6,286. Crew size for the carrier of the future may be even lower. On some classes, manning varies considerably depending on the mission. This is especially true for amphibious ships and aircraft carriers which more than double their crew sizes when a marine contingent or air wing is onboard.

Waste Streams

An understanding of the waste streams to manage and the processes that generate them is the next key factor in designing the ESW 21. While there are numerous individual waste streams generated onboard ships and as a result of their life cycle, most can be grouped into seven main categories: blackwater, graywater, oily wastewater, air emissions, solid waste, medical waste and hazardous materials. U.S. Navy ships, technically, do not generate hazardous waste, but they do produce HAZMAT in normal operations that are collected and managed for eventual return to shore. HAZMAT is also generated in the manufacture, maintenance, and disposal of Navy vessels. The Carderock Division of the Naval Surface Warfare Center (CDNSWC) has conducted numerous shipboard environmental quality studies to determine waste stream categories, constituents, and generation rates. Table 4 provides the source and generation rates for the seven main waste stream groups produced by an operating ship and the projected percent reduction of these that should be possible in the future.

Table 4: Shipboard Waste Generation Rates

Waste	Source	Generation Rate	Future Reduction
Blackwater	Toilets and Urinals	30 gal/per-day (gpd)CHT 3 gpd VCHT	CHT - 90% VCHT - None
Graywater	Showers, Laundry, Sinks	30 gpd	50%
Bilgewater	Shaft Seal Leakage, Pipe Sweat, Machinery/Equipment Leakage	2000 gpd for DDG 51 Class 3000 gpd for CVN 68 Class	50%
Solid	Food Preparation, Supplies, etc.	3.19 lb/per-day	50%
HAZMAT	Operation, Repairs, Maintenance, etc.	Variable – Ship Class Specific	50%
Air Emissions	Propulsion Systems, Refrigeration Systems, Painting, etc.	Variable – Equipment Specific	Unknown
Medical	Hospital, Dental	Variable – Ship Class Specific	Unknown

Collecting generation rate and waste stream constituent information is not an exact science; data collected exhibited wide variability. Generation is influenced by a variety of factors including ship operations, menu served, time of year, personnel onboard, area of operation, and the waste management strategies employed. Sampling technique and cooperation of ship's force also influence the data collected during a survey. As shown above, some waste streams are so variable that meaningful per capita or per unit time rates cannot be determined.

The solid waste stream is the most studied and understood at present. CDNSWC has conducted approximately ten solid waste generation, characterization, and demonstration studies in the past decade, principally, to optimize development of the Navy's current solid waste management equipment. The design values were selected based upon statistical analysis of data collected by CDNSWC, and are given in Table 5. The most detailed shipboard solid waste study was the solid waste flow analysis conducted by the Naval Sea Systems Command (NAVSEA) aboard USS *John C. Stennis* (CVN 74) from 18 – 31 October 1997. This two week study measured all solid waste processed in each of the six solid waste processing spaces aboard the aircraft carrier and determined when the waste was delivered and where it came from by compartment and division. This data established revised design values for the CVN 68 Class and enabled determination of optimum equipment numbers, installation locations and equipment operating times. Over 104,000 pounds of solid waste in nine categories was measured. The overall observed generation rate of 1.64 pounds/person-day represents a forty-nine percent reduction in waste generation from the original design premise of 3.19 pounds/person-day. This reduction is attributed to ship initiatives to reduce solid waste, Navy Pollution Prevention initiatives, re-evaluation of economies of scale, and an unexplained reduction in observed food waste generation – twenty-five percent of expected (Markle and Gill 1998).

Table 5: Navy Solid Waste Design Generation Rates

Waste Type	Weight Rate*	Volume Rate**
Food	1.21	0.03
Paper/Cardboard	1.11	0.19
Metal/Glass	0.54	0.05
Plastics	0.20	0.15
Wood	0.01	<0.01
Textiles	0.12	0.01
TOTAL	3.19	0.43

* - Weight Rate given as pounds/person-day
** - Volume Rate given as cubic feet/person-day

The lessons learned (or confirmed) during the study aboard USS *John C. Stennis* (CVN 74) were: locate equipment as close as possible to waste generation sites, only operate it around meal hours, logistics activities produce the greatest amount of waste, and reduce the amount of waste by implementing source reduction measures. The designers of the ESW 21 need to apply those lessons that are known and conduct the necessary research to learn what is not known.

Ship Design Premises

The design team must consider all environmental requirements, the environmental impact from all ship systems, and the operational and performance factors in any new ship design. To optimize the ship design to minimize the environmental impact while also minimizing the total life cycle cost of compliance the designer must fully integrate the waste generating activities and management techniques or processing equipment for all aspects of the ship's life. Waste minimization techniques, procedures and equipment should be employed. Environmentally friendly materials of construction should be selected. The ship should be configured to collocate waste generating activities and processing equipment, minimize waste transport distances, ensure adequate access to disposal points, and allow collection of all wastes. Management procedures or processing equipment should be utilized for all waste streams onboard and throughout the life cycle. Technologies employed must allow wastes to be treated or destroyed onboard to the maximum extent practicable, have no inappropriate dependence on shore facilities for waste offload and disposal, and minimize the logistical costs for waste management.

Waste Management Equipment Design Issues

The design and development of waste management equipment for U.S. Navy warships requires the consideration of a number of factors not considered in the design of similar equipment for use on commercial vessels or ashore. These factors are centered on ship operational profile, operational environment, the way these warships are managed, personnel available to operate and maintain waste processing equipment and fleet size. U.S. Navy warship operations are unique, as instruments of public policy, they are operated to conduct sustained naval presence and prevail in time of conflict. These operations often require them to be deployed for extended periods of time to the far corners of the world and to operate in a hostile political and natural environment. Warships are away from their homeports for extended periods and ports of call are frequently over one month apart. This requires a high degree of self-sufficiency and support from a long logistical support chain. In common with commercial vessels, the environmental quality management techniques and equipment used cannot detract from the ship's operational readiness, range or access to the world's oceans. In addition, the ship's crew cannot be endangered by any undue health or safety risk, nor have a reduction in their quality of life, both of these will lead to decreased ship operational efficiency. Finally, ESW 21 total ownership cost must be minimized.

The selection and development of appropriate warship equipment must ensure that all potential solutions are considered with fleet input and operational and design constraints. Usually there are numerous potential technological solutions for the management of wastes, but only a small portion are suitable for naval applications. The fleet understands the shipboard management problem first hand, and has substantial knowledge on the benefits and burdens of potential technologies. Operational and design constraints govern the shipboard integration of all potential solutions. While all three areas are important, only when they are taken together can the best solution be identified. That solution is the intersection of the three areas or the "Goal" shown in Figure 6.

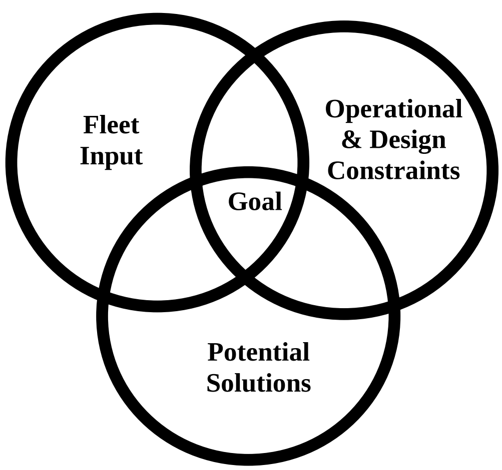

Figure 6. Design Requirements Interaction

A number of factors must be considered when developing equipment for U.S. Navy warships. These factors are provided in Table 6, and include: ability to process the types and quantity of waste; performance in the shipboard environment; requirements placed on the ship (men, space and services); and effects on ship operations. Some factors are warship specific, such as equipment status when “General Quarters” is sounded. A design decision must be made to either incorporate rapid equipment shutdown to a safe condition, or if not possible, plan to occupy the space during “General Quarters,” preventing at least one able body from carrying out a potentially more critical warfighting task.

Table 6: Waste Management Equipment Design Factors

♦Performance	♦Health and Safety
•Process Rate	•Process or product creates fire/explosion hazard
•Operability/Reliability/Maintainability/ Survivability	•Uses toxic/hazardous substances
▫Shock and Vibration	•Mechanical/physical hazards
▫Ship motions	•Process creates toxic/hazardous by-product
▫Repairable by ship’s forces with minimal training	•Generates excessive noise
▫Marine atmosphere/environment	•Firefighting requirements for process/by-product.
•Military mission/operations/readiness	♦Manning
•Easy to secure for general quarters	•Equipment operation and maintenance
•Emissions	•Waste sorting, movement, stowage and offload
•Secondary waste stream handling and disposal	•System management
•HAZMAT usage/requirements	•Skill level/training requirements
•Excess HAZMAT generations	•Crew turnover
♦Weight	•Human engineering factors
♦Ship Integration	•Habitability & morale
•Structural modifications	•General quarters manning requirements
•Equipment breakdown or ship cutouts	♦Costs and Risks
•Rigging requirements	•Technology development including logistics
•Ship services	▫New technology
▫Electrical power systems	•Conversion to marine/Navy use
▫HVAC systems	•Ship alteration/integration design
-Equipment heating/cooling	•Procurement
-Space heating/cooling	•Installation
-Process exhaust	•Operations
-Waste odor exhaust	▫Manning
▫Fluid systems	▫Utilities/consumables
-Water (fresh/sea, hot/cold)	▫Secondary product disposal
-Process	▫Maintenance/repair/overhaul
-Cooling	▫Logistics
-Maintenance	•Programmatic/Political
-Fuel	♦Arrangements
-Hydraulics	•Footprint, height, volume
-Steam and condensate	•Number of decks
-Pneumatics	•Waste pre-process staging
-Drainage	•Waste post-process storage
♦Commonality of systems/components	•Secondary waste storage
•Within this piece of equipment	♦Ship signatures (infrared, acoustic, electromagnetic)
•Within the Navy	♦Electromagnetic compatibility (EMI/EMC)

Equipment processing rate depends on type of waste stream, waste generation rate, number of personnel generating the waste, number and type of equipment, equipment operating hours, time to repair the equipment and equipment reliability. Processing rate for waste equipment requiring human interaction is as dependent on the operator's performance as it is on equipment characteristics, the rate will suffer if the operator does not load the equipment as fast as it will allow. Equipment selection must be based on the average processing rate achievable by a range of operators, processing a mix of appropriate wastes and not on the peak process rates for a select type of material.

Waste management equipment operability, reliability, maintainability and availability aboard U.S. Navy ships is critical. These warships must have equipment capable of meeting the ship's waste generation demand. This requires reliable equipment and, if failure occurs, it must be maintainable by ship's forces without excessive manpower or delay. Terms used to describe this are: Mean Time Between Failures (MTBF), Mean Time Between Critical Failures (MTBCF), Mean Time to Repair (MTTR) and Mean Logistical Delay Time (MLDT). MTBF and MTBCF are indicators of the equipment's reliability. Ideally, these should both be as long as possible, five hundred hours of equipment operation between failures is not uncommon. MTTR and the MLDT indicate the degree of equipment maintainability, both should be as low as possible. MTTR is dependent upon equipment design, installation design and crew training. MLDT is a measure of how long it takes for repair parts to be obtained. While this could easily be minimized by carrying excessive quantities of spare parts onboard, this is impractical. Having a good engineering sense of the processes, equipment and materials and their optimization can also minimize MLDT. This understanding, coupled with testing, provides insight into the components most likely to fail in-service allowing for design optimization and intelligent sparing.

Equipment must be able to survive and operate properly in the shipboard environment. This hostile environment can cause operational problems and premature failure in equipment that would be acceptable for land based application. A ship's movement through the water requires equipment operation while moving, accelerating and decelerating in six degrees of freedom. This motion along and about its three axis {Surge (longitudinal), Sway (lateral), Heave (vertical), Pitch, Roll and Yaw}, requires the equipment to be safe to operate even while rolling and pitching over fifteen degrees from horizontal. These changes in inclination must be taken into consideration when considering liquid levels and retention or damping of movable components. The acceleration and deceleration caused by ship motions exerts forces on the equipment that are much greater than any internal operational loads. These loads necessitate consideration of the location of masses within the equipment and how these masses are retained or contained during ship's motion. This may require the lowering of the equipment center of gravity, widening of mounting footprints; elimination of cantilevered masses and requiring additional support structure over what would be required in land based installations. In addition to gross ship motion, the equipment will be exposed to vibrations generated by the rotation of the propeller shaft in the water and other nearby operating equipment. The most frequent failure mechanism experienced due to ship motion is premature fatigue failure of components or structure.

To ensure the equipment is capable of surviving ship motion, it must successfully pass shock and vibration testing. Vibration testing to Military Standard MIL-STD-167/1 is performed on equipment to ensure that it will remain fully operational while encountering continuous and prolonged vibrations. During testing, the equipment (mounted, as it would be found installed onboard ship, including all associated piping) is energized and operating. The equipment is vibrated at the frequency specified in Military Standard MIL-STD-167/1, in each of its three axis for a period of two hours or until failure. The equipment must also be capable of withstanding the shock due to an explosion. Shock testing is performed in accordance with Military Specification MIL-S-901D (NAVY). Waste management equipment is expected to meet Grade B requirements, for those systems or equipment that are not mission critical, where the equipment can be rendered inoperable, but components cannot fly free when exposed to shock loads. It is critical that Grade B equipment not endanger the crew or other ship critical systems due to shock failures.

The equipment must be electromagnetically compatible with other ship systems. The severe electromagnetic environment experienced onboard must not degrade the performance of the equipment. This includes not only the proper operation of the equipment, but also the system cannot be inadvertently energized or de-energized due to electromagnetic susceptibility. Likewise, limits are placed on the electromagnetic emissions generated by all equipment to prevent affecting the operations of other shipboard equipment or systems.

Equipment airborne and structureborne noise generation is strictly controlled aboard warships. This is most critical on ships used for anti-submarine warfare. Excessive noise from equipment, coupled either through the air to the ship's structure and then into the water or directly through the ship's structure into the water, could degrade the performance of the ship's hydrophones. Additionally, noise generated by the equipment could necessitate the wearing of hearing protection in the space and degrade operator quality of life. Equipment noise is typically generated by rotating machinery and amplified by poorly designed equipment structure or items such as belt guards. Sound mounts and dampening materials are frequently used to minimize the noise level generated. Care in equipment installation will minimize noise emissions.

Material corrosion and fouling are two issues that must always be considered. The warm, humid air in which this equipment must operate has a high salt content making it highly corrosive to most materials. In addition, the waste materials the equipment will process can also be highly corrosive to some materials. Care must be taken to minimize the contact of dissimilar materials or galvanic corrosion will cause damage. The designer must also take care to minimize crevices in the design or crevice corrosion will quickly cause failure. Corrosion preventative coatings must be utilized with care, as a failed coating system may actually promote the corrosion it was intended to prevent. Adherence to marine environment design practices is a must for the success of all shipboard equipment design engineers.

The equipment's service requirements must also be evaluated. The quantity and type of electrical power required to power and control the equipment must be considered. The need for high power demands and/or the addition of specialty power conditioners and transformers should be avoided. Heating, Ventilation, and Air Conditioning (HVAC) demands for the process, the space and all associated staging and storage areas must also be included in the design. If ESW 21 includes Collective Protection System (CPS) allowance must be made for individual waste management equipment ventilation exhaust piping to the weather deck. An assessment of the hazards (chemical and spark, temperature, odor, clarity, and exhaust fly ash content) from equipment and its operating space must also be performed. This may govern exhaust routing and limit operation times to prevent interference with other shipboard operations, such as flight operations. System requirements must consider fluids entering into the process (e.g. fuel), fluid passing through the equipment for cooling, processing or maintenance and the drainage of all liquid by-products.

Some ships have mission specific requirements effecting equipment design and production. Minesweepers have very strict requirements that minimize the use of magnetic materials. This limits the use of ferrous materials in equipment designs and controls other magnetic aspects of the design.

The final performance characteristic that requires consideration is equipment by-product or emissions. The nature of the emission (solid, liquid and gaseous) may greatly effect its acceptability. If the process creates hazardous or toxic waste, the cost (financial and political risk) may prohibit any further consideration. The political and biological impact of all discharges into the ocean must be considered carefully when analyzing alternatives, in some cases a detailed assessment required by the NEPA must be performed. The density, stability, long-term storage parameters and ashore disposal requirement of waste by-products must be considered when examining whole ship impacts. This might include ash generated in an incineration process, sludge from a liquid waste concentration system, or the disks produced by the Plastic Waste Processor.

Ship Arrangement and Human Factor Issues

Location of the waste management equipment aboard ship can greatly affect its effectiveness. The single most important decision that will effect manpower requirement is the location of waste management equipment relative to waste generation sites. A rigorous systems analysis of the waste sources should be conducted as part of the ship arrangement study for ESW 21. Data analysis shows candidate areas where equipment should ideally be located. For solid waste, equipment should be located adjacent to the crew mess decks. To enhance traffic flow, designs should also incorporate two accesses, an entrance and an exit.

Equipment integration into the ship structure must also be considered when evaluating any waste management alternative. Structural modifications may be required to support equipment weight or to alter space layout, as suitably sized spaces may not be available. If possible, the equipment should be hatchable, designed to be easily rigged through the existing 26 inch wide by 53-inch high shipboard doorways, whole or as modules, avoiding costly hull cuts in the event of removal for overhaul.

Human system integration into the design of shipboard systems and equipment is of great importance. While it can be expected that U.S. Navy warships will have highly qualified, motivated personnel operating and maintaining the waste management equipment, the prudent designer must design for the worst case. High crew turnover rates must be counted on, necessitating the design of easy to operate and easy to maintain equipment, requiring only minimal training. Man machine interfaces must provide accurate equipment status, ease of operation, and assist in problem isolation and correction.

Health and safety considerations impact all equipment and processes and are carefully reviewed. Processes that increase the risk of fire must be carefully investigated to determine if all risk mitigation measures have been incorporated into the equipment design, operating procedures, crew training and space design. In addition, fire fighting and containment systems must be designed into the space. The use or generation of toxic, flammable or otherwise hazardous substances must be avoided. The incorporation of safety lockout (inter-locks), warning labels, and warnings/cautions in design, technical documentation and in training materials is required. Safety devices must be inspected and maintained in a constant state of readiness to avoid personnel injury or equipment damage. Equipment operators might be required to wear some form of personnel protective equipment including gloves, ear protection, face shields, safety shoes, and/or apron.

Total ownership cost for each alternative must also be considered and compared. When discussing cost, one must consider not only the monetary cost, but also consider the parallel risk involved. The development of technology can require substantial investment. This is true for the development of a new technology and also for the conversion of existing technology for naval/maritime application. These costs involve design, engineering, laboratory development and qualification, preparation, verification, and validation of a large quantity of vital and necessary logistical documentation (see Table 7) and finally extensive shipboard testing and evaluation. While the cost for equipment acquisition might be large, costs incurred involving design, preparation and installation of the equipment are typically greater. Once integrated into the ship, expenses continue to accrue as operation and maintenance costs. These costs are for consumables, utilities, logistic support, maintenance, repair, overhaul, final disposal of the processed waste, and deactivation costs. The major cost driver for waste management equipment is the operation and maintenance cost associated with manpower, reductions in manpower result in greatly reduced total ownership cost. This cost includes the manpower required to: provide source separation, waste transportation, equipment operation, equipment maintenance, processed waste/secondary product handling and storage, waste offloading from the ship, disposal costs, and the overall waste management function. Finally the programmatic/political costs and risks must be carefully assessed throughout the test, evaluation and integration of all waste management alternatives.

Table 7: Typical ILS Documentation Demands for U.S. Navy Shipboard Equipment

♦Failure Modes, Effects, & Criticality Analysis	♦Definition of Maintenance Facilities Requirements
♦Level of Repair Analysis	♦Packaging, Handling, Storage & Transportation Requirements
♦Reliability Centered Maintenance Analysis	♦Supply Support Packaging, Handling, Storage & Transportation
♦Identification of Human Engineering Requirements	♦Task / Skill Analysis
♦Navy Training Plan	♦Training documentation
♦Quality Assurance Plan	♦Reliability Centered Maintenance Preventive Maintenance Schedule
♦Systems Safety Plan	♦ Inter-active Courseware {Training Requirements}
♦Hazard Analysis	♦Source, Maintenance & Recoverability Codes
♦Technical Manual Validation Plan	♦Allowance Equipage List
♦Technical Manual	♦Allowance Parts List
♦Support Equipment Requirements List	♦ Human Engineering Analysis
♦Support Equipment Stowage Requirements	♦ Acoustics tests reports
♦New Equipment Calibration Requirements	♦Shock and vibration test reports
♦Calibration Procedures	♦EMI/EMC test reports
♦Depot Maintenance Plan	♦Provisioning Technical Documentation

It is expected that a greater percentage of future equipment entering the fleet will be COTS or COTS derivatives modified for U.S. Navy shipboard use. In the selection of waste management equipment from land based technologies or marine technologies, COTS products or emerging technologies should be considered, but substantive analysis and qualification (filtering) is generally required prior to being integrated into the warship design, as depicted earlier in Figure 1. The alternative must meet the performance requirement, be suitable for the marine/naval environment, minimize ship impact, require or generate no hazardous material, be low maintenance, reduce manning, and be affordable.

U.S. NAVY COMPLIANCE STRATEGIES

The U.S. Navy's compliance strategy revolves around two main philosophies: pollution prevention and pollution control. Pollution prevention, “before-the-pipe,” seeks to minimize the amount of waste produced using innovative procedural and management approaches and commercial off the shelf (COTS) waste minimization equipment. Pollution control, “end-of-pipe,” uses management techniques and state-of-the-art treatment technologies to process waste for discharge or retention in compliance with environmental laws.

Pollution Prevention

Pollution prevention can be divided into two main areas: source reduction and waste minimization. The former is designed to identify materials (e.g. plastic packaging) and consumables (e.g. rags) that become waste and reduce or eliminate their use with alternative materials and/or processes. Studies have shown that fifty-two percent of solid waste generated shipboard is packaging related, and forty-eight percent is non-packaging (NAVICP 1997). The Naval Supply Systems Command's (NAVSUP) Plastics Removal in the Marine Environment (PRIME) and Waste Reduction Afloat Protects the Sea (WRAPS) Programs are examples of Navy source reduction initiatives. PRIME targets the high volume plastic items identified in CDNSWC Plastic Waste Characterization Studies for substitution with non-plastic items. The program also vigorously investigates alternative packaging and packaging methods to significantly reduce or eliminate plastic packaging materials. The PRIME Program has made packaging changes to 611,400 items reducing the amount of plastic material used which has resulted in less plastic waste for ships to process and store. WRAPS has identified numerous packaging methods (other than plastic) for substitution or modification to reduce the amount of waste that is generated and must be processed. These include identification of alternatives to shipboard use of fiberboard: Bulk Reusable Shipping Containers (replacing cardboard “Tri-Walls”), Reusable Food Totes, and Reusable Can and Cylinder Totes. Also being investigated are reusable mailing/shipping containers, and biodegradable plastic-like materials for use as eating utensils and food containers, and methods to reduce the amount of “junk” mail received by afloat units.

Minimization of hazardous waste shipboard is the objective of the Pollution Prevention (P2) Afloat Program. This is accomplished by identifying those processes that generate hazardous waste and then acquiring COTS equipment to reduce or eliminate the particular hazardous waste stream. This program will result in greatly reduced hazardous material to inventory, store, and dispose of ashore.

Pollution Control

The Navy's Pollution Control Program develops techniques and processing/treatment equipment to effectively manage the various waste streams produced and the environmentally sensitive materials employed in shipboard operations. This program addresses the following waste streams, materials, and concerns: solid waste (i.e. paper, plastic, glass, etc.), liquid waste (i.e. sewage, graywater, oily wastewater, etc.), air emissions (from engines, incinerators, etc.), hazardous materials, ozone depleting substances, paints and preservation systems, and the accidental introduction of non-indigenous species.

Solid Waste and Solid Waste Processing Equipment

In April 1993, the Navy Solid Waste Management Program was formally established, implementation has been the responsibility of the Engineering Directorate of NAVSEA. The “Solid and Plastics Waste Management Program Plan,” developed by NAVSEA, provided the blue print for development, acquisition, and Fleet-wide installation of solid waste management equipment intended to process all non-hazardous solid waste generated aboard surface ships (NAVSEA 1993). CDNSWC and NAVSEA engineers, with manufacturing and logistic support provided by Westinghouse Machinery Technology Division, successfully executed a two-year development program for four unique machines. These are the Large Pulper (LP), Small Pulper (SP), Metal/Glass Shredder (MGS), and Plastic Waste Processor (PWP). Each has been designed to handle a specific portion of the solid waste stream and have gone through extensive test and evaluation prior to Fleet introduction. The Solid Waste Equipment operational concept is provided as Figure 7.

Crew training for operation and maintenance of this equipment represents a change in Navy philosophy. For the first time, land based classroom "hands-on" training is not being offered. Rather, the Navy has developed a comprehensive program using Interactive Computer Based Training (ICBT) on CD-ROM. The technical manuals for this equipment were developed to complement the ICBT. To facilitate Fleet introduction, a detailed "Shipboard Solid Waste Management Equipment Guide" (CDNSWC 1997), several videos, periodic "lessons learned" conferences, and an Internet web site have been developed and maintained (SEIC). The single greatest challenge is to foster a sense of ownership for this equipment on the part of the Fleet sailor for whom it was designed and installed for. Shipboard training should not be limited to only the operators and maintainers. The entire ship, top to bottom, must be trained in waste minimization, source separation and in the understanding of how and why we are managing the shipboard generated waste stream.

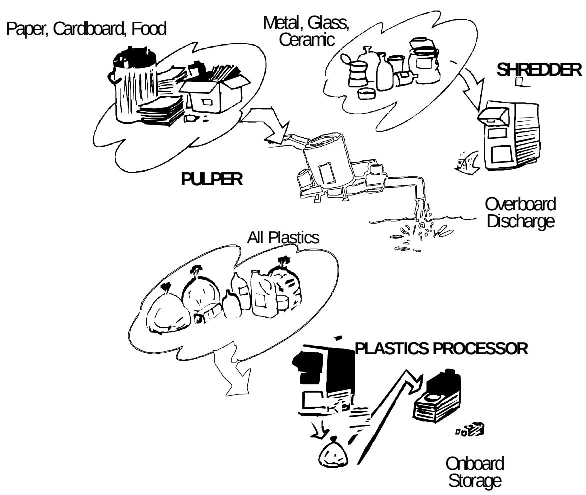

Figure 7. Solid Waste Equipment Operational Concept

Plastic Waste Processor

The PWP was designed to process all shipboard generated plastic waste into a greatly reduced volume, stable product for storage onboard. Navy research teams determined that this was best accomplished using the following steps in series: shred, compress, and melt. A Solid Waste Shredder (SWS) or Plastic Shredder was developed to shred the plastic waste. The compress and melt functions were combined into a batch process heated compactor called the Compress Melt Unit (CMU) and a Closed Loop Cooling Unit (CLCU) was designed to remove the heat from the melted plastic product and increase process rate.

The PWP, Figure 8**,** achieves a thirty-to-one volume reduction by processing all plastic waste (food and non-food contaminated) into twenty-inch diameter, approximately 1.5 inch thick, disks. The plastic disks are then heat sealed into Navy developed Odor Barrier Bags (OBBs) for long-term storage to minimize odors and preclude vermin problems until they can be offloaded for shore disposal.

Figure 8. Compress Melt Unit and Plastic Disk

The PWP is usually composed of two or more CMUs, a CLCU for every two CMUs, and, in most installations, a SWS, which can service up to six CMUs. The SWS is virtually identical to the MGS and shreds the plastic at a rate of eighty pounds-force/hour (lb/hr) prior to processing in the CMU. Shredding performs an initial four-to-one volume reduction, breaks down large objects that wouldn't fit in the CMU, liberates trapped liquids and food waste, and homogenizes the plastic waste which results in better disk quality (i.e. a disk that retains its shape and does not fall apart) and higher overall PWP processing rate. The CMU melts the polyethylene portion of the plastic waste (approximately seventy-percent of all shipboard plastic waste) and provides the compaction force to make the disk. A PWP equipped with SWS can process approximately ten lb/hr per CMU.

The PWP can be scaled to any ship class by adding more equipment. For example, the PWP onboard the *Arleigh Burke* (DDG 51) Class is composed of two CMUs, one CLCU and a SWS; *Nimitz* (CVN 68) Class aircraft carriers have an average of eleven CMUs, seven CLCUs, and three SWSs. The equipment suite selected for each ship class enables complete processing of all daily plastic waste generated in about six hours.

The 1994 NDAA provided direction to the Navy in the form of Congressional Milestones. These milestones required execution of an aggressive acquisition and installation schedule. The Request For Proposal (RFP) date was to occur no later than 1 October 1994, first ship installation no later than 1 July 1996, twenty-five percent completion (forty-eight ships) by 1 March 1997, fifty percent by 1 July 1997 (ninety-six ships), seventy-five percent by 1 July 1998 (143 ships) and completion by 31 December 1998 (191 ships). The $400 Million PWP Program met or exceeded all requirements, with all required Navy ships being outfitted with PWPs as required by U.S. Law (Markle et al. 1999).

Shredder

The MGS, Figure 9, shreds metal waste (primarily aluminum soda cans and steel food containers) into thin strips and fractures glass waste into pieces. The shredded product is placed in burlap bags forming a non-buoyant package for overboard discharge when greater than twelve nautical miles from shore. The MGS has a machine-processing rate of 600 lb/hr. Most metal and glass waste is generated in the galley/mess area and represents approximately eighteen percent of the solid waste generated by weight. At least one MGS will be installed on all ships FFG 7 Class and larger.

Figure 9. Metal Glass Shredder Operation

Pulpers

The Pulpers are designed to process paper, cardboard, and food waste; they also serve as a paper classified documents destructor. The waste material is fed into the pulper where it is mixed with seawater and ground up into small particles that are then discharged overboard via an eductor when greater than three nautical miles from land. The LP, Figure 10, has a mixed waste-processing rate of 680 pounds-force/hour (lb/hr); the SP, Figure 10, can process 140 lb/hr of mixed waste. Historically, approximately seventy percent of the solid waste generated aboard ship is pulpable and most of this comes from the galley/mess areas.

Figure 10. U.S. Navy Large Pulper Operation

Figure 11. Small Pulper Operation

A single LP can process the daily pulpable waste generated on an *Arleigh Burke* (DDG 51) Class ship in approximately one hour of operation.

Ship Class Equipment Suite

The suite of four equipment types was designed to fit twenty-seven U.S. Navy ship classes, in various equipment mixes. Equipment mix was determined based upon the following major factors: crew size, waste generation rate, equipment throughput rate, ship mission duration, and equipment reliability factors. The goal was to select the optimum numbers of equipment that would reliably process all waste over the expected mission duration. In some cases, programmatic compromise balanced the competing needs of reliability analysis with the reality of backfitting this equipment into volume/space limited existing warships. Siting of equipment was dependent upon waste generation locations as compared with overall ship arrangement impact, and effects on ship quality of life. Table 8 provides the equipment suite for each class of ship. Ships smaller than *Oliver Hazard Perry* (FFG 7) Class lack the space and weight for equipment installation, and some ships such as USS *California* (CGN 36) and USS *Spruance* (DD 993) are being decommissioned, so that Pulper and MGS installations will not be performed.

Table 8: U.S. Naval Ship Solid Waste Equipment Mix

Ship Class	Solid Waste Equipment (# of units per ship)					
	Metal Glass Shredder	*Large Pulper*	*Small Pulper*	*Plastic Shredder*	*Compress Melt Unit*	*Incinerator*
AGF 3	1	1	0	1	3	0
AO 177	0	0	0	1	3	0
AOE 1	1	1	0	1	3	1
AOE 6	1	1	0	1	3	1
ARS 50	1	0	1	0	1	0
AS 39	1	1	0	1	4	0
CG 47	1	1	0	1	2	0
CGN 36	0	0	0	1	3	0
CV	1	2	1	2	11	1
CVN 65	1	2	1	2	11	1
CVN 68	1	2	1	3	9 to 14	1
DD 963	1	1	0	1	2	0
DDG 993	0	0	0	1	2	0
DDG 51	1	1	0	1	2	0
FFG 7	1	0	1	0	2	0
LCC 19	1	1	0	1	3	0
LHA 1	1	1	0	1	6	0
LHD 1	1	1	0	1	6	0
LPD 4	1	1	0	1	3	0
LSD 36	1	1	0	1	3	0
LSD 41	1	1	0	1	3	0
MCM 1	0	0	0	0	0	0
MCS 12	1	1	0	1	3	0
MHC 51	0	0	0	0	0	0
PC 1	0	0	0	0	0	0

Incinerators

Several ship classes have Vent-O-Matic Incinerators, built to Military Specification MIL-I-15650**,** installed on them. These incinerators are refractory lined burn boxes equipped with a blower. They have no auxiliary fuel, combustion control or emissions monitoring and treatment systems. While they can process several waste types the other solid waste equipment cannot such as textiles, non-hazardous oily rags, and wood, they have a slow processing rate, and have proven to be a safety, reliability, and maintenance challenge. In typical Navy shipboard applications, it is not unusual for the refractory lining of these incinerators to fail within six months of use.

There are numerous commercially available marine incinerators today that do not have the maintainability issues exhibited by current Navy Incinerators. These new systems boast significant improvements over models tested by the Navy in the early 1980's. The Navy evaluated four Incinerator concepts in preparing the 1996 Report to Congress (U.S. Department of the Navy November 1996). Each system investigated was evaluated for use on large combatant ships (*Ticonderoga* (CG 47) Class), auxiliary ships, amphibious ships and aircraft carriers. Subsequent ship impact studies of large three and four deck marine incinerators were deemed infeasible without adding a new section to the ship, because the system required too much internal hull volume. Cost analysis performed on these systems showed them to be uneconomical when compared to other waste management technologies. Smaller incinerators were also evaluated, but similar analysis showed that more units would be required, increasing overall ship impacts, equipment costs, and operation and maintenance costs. Other concerns with regard to air emissions, including uncertain future regulatory controls and human health considerations, have contributed to the Navy not adopting current marine incinerator technology. Even if these new generation marine incinerators could be economically installed, there still exists a significant risk associated with stack emission requirements, especially in highly regulated air pollution control regions.

Liquid Waste and Liquid Waste Processing Equipment

Liquid waste is composed of three main categories: blackwater (sewage); graywater derived from commissary, laundry, and shower/sink use; and oily wastewater represented principally by bilgewater. These three waste streams are generated in large volumes and pose a significant management challenge for the Navy. Figure 12 depicts a schematic of current Navy wastewater management discharge schemes.

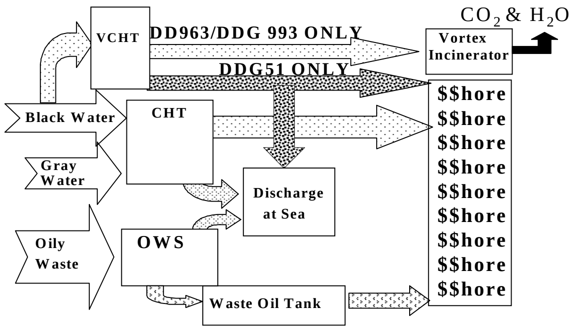

Figure 12. Current Liquid Waste Treatment Methods

Blackwater Processing Equipment

The Navy currently employs a simple strategy for managing blackwater on most of its ships. Because the discharge of blackwater is only prohibited within three nautical miles of shore, appropriately sized holding tanks are employed to collect and hold all the sewage generated while the ship transits the no discharge zone. On seawater flush, gravity drain systems, this is called the Collection, Holding, and Transfer (CHT) system. These tanks are equipped with level sensors and pumps which are set to operate automatically once the ship proceeds beyond the 3 nautical mile zone. A variation of this concept employs reduced volume, freshwater flush fixtures and a vacuum collection system called the Vacuum Collection, Holding, and Transfer System (VCHT). The VCHT system uses ninety percent less water than the CHT system resulting in significantly reduced generation rates, but more highly concentrated blackwater. The VCHT system is also lighter (due to smaller diameter collection pipes and smaller volume collection tanks) and offers an additional degree of installation flexibility over gravity drains. It is expected that ESW 21 will employ a VCHT system for blackwater.

Only two classes of Navy ships have blackwater treatment systems in place: the *Tarawa* Class (LHA 1) and the *Spruance* Class (DD 963). The *Tarawa* Class is outfitted with three activated sludge sewage treatment plants. The design premise behind these is much like municipal sewage treatment plants in that they employ aeration, biological treatment, clarification, and chlorine disinfection of the effluent. In practice, however, they have proven to be difficult to operate, and are being converted to CHT systems. The *Spruance* Class is equipped with a VCHT system and two Vortex Incinerators which provide the option of burning the blackwater collected in lieu of discharging it overboard or to a pier connection when in port. These incinerators use auxiliary fuel, Diesel Fuel Marine, and are rated at 0.5 gallons per minute throughput. Atomized fuel and high velocity combustion air are mixed in a recirculation chamber designed to draw hot gases from the combustion chamber and superheat the mixture to the ignition temperature. Rising overseas sewage disposal costs have resulted in increased use of the Vortex Incinerators, and a Navy Research and Development (R&D) program is in progress to enhance their operation. Upgrades were recently tested on USS *Thorn* (DD 988) and USS *Briscoe* (DD 977) with excellent results. It is expected that an advanced Vortex Incinerator will be integral to the ESW 21. Figure 13 illustrates the Advanced Vortex Incinerator under development at CDNSWC.

Figure 13. Advanced Vortex Incinerator

Graywater Processing Equipment

Currently, the Navy does not treat graywater prior to discharge. However, with individual States using the CWA to set receiving water quality standards and UNDS Program identifying graywater as a discharge for regulation, ESW 21 will likely require management of this waste stream. Currently, all ships equipped with CHT systems have the capability to divert their graywater to the CHT tanks, which would then be discharged overboard beyond three nautical miles of shore or sent to a pier connection, when the ship is in port.

The UNDS Program will ultimately set discharge limits for graywater, but the Navy is aggressively pursuing treatment technologies to develop practical, affordable systems now. The present effluent quality goals are 50 milligrams/liter Biochemical Oxygen Demand (BOD_5), 100 milligrams/liter Total Suspended Solids (TSS), and 200 colony forming units of fecal coliform bacteria per 100 milliliters. Two low flow treatment systems, less than three gallons-per-minute (gpm), are currently being evaluated in the laboratory; both are biological treatment based and employ ultrafiltration membranes. While they are configured differently, each uses an aerated bioreactor to biologically reduce the BOD_5 and membranes remove the TSS and most of the fecal coliform bacteria. They also use ultraviolet light as a secondary treatment process to further reduce the fecal coliform bacteria in the effluent to below goal levels. Each system is only in the early development stages but they have proven that this is a viable approach to graywater treatment (Demboski 1997). Figure 14 shows the graywater membrane ultrafiltration system under development at CDNSWC.

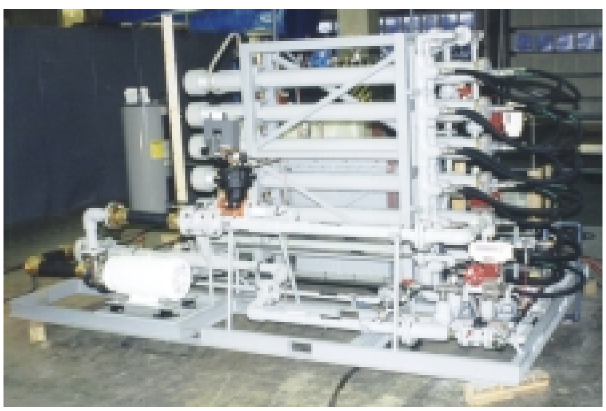

Figure 14. Graywater Ultrafiltration Membrane Treatment System

Oily Waste Processing Equipment

The principal source of oily wastewater from Navy ships is bilgewater, although UNDS has recently identified several other oily wastewater sources that may be regulated in the future. Bilgewater generation and oil content is influenced by many factors including ship class, operating condition, equipment casualties, maintenance, etc. Bilgewater generation surveys have found that rates can vary from as little as 100 gpd to more than 50,000 gpd (although 2,000 to 3,000 gpd is a reasonable average) and the oil content can range from several ppm to twenty or more percent (one percent = 10,000 ppm). It is expected that ESW 21 will be a “dry bilge” ship and not produce a great quantity of bilgewater.

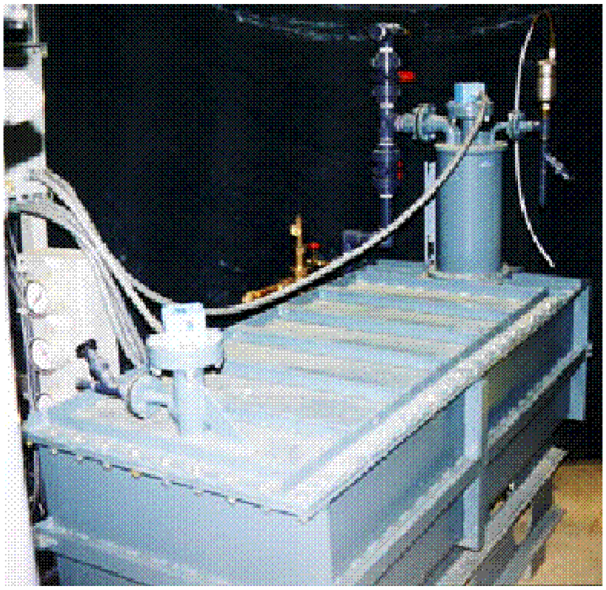

Figure 15. 10NP Gravity/Parallel Plate Oil Water Separator

Several oil/water separation systems have been developed and deployed to the Fleet over the past two decades. All Navy ships are equipped with oil water separators (OWSs) to process bilgewater. Most are the 10-NP parallel plate gravity OWS (Figure 15) and the C-50 centrifugal separator. The ten gpm 10-NP OWS is installed on most small combatants and auxiliaries and the C-50 (fifty gpm processing rate) is installed on the larger amphibious ships and aircraft carriers. Both perform well when processing non-emulsified oil. OWSs are usually installed with an oil content monitor (OCM) to evaluate the quantity of oil in the effluent. The ET-35N OCM is used in all Navy installations. This OCM is a simple turbidity meter, evaluating the turbidity in the effluent and comparing that to a standard to determine oil concentration. Effluent with oil concentrations greater than that allowed by law is recirculated back to the oily waste holding tank while effluent containing oil concentrations less than that allowed by law is discharged overboard.

Neither of the separators currently in use can effectively remove emulsified oil nor heavy metals or a myriad of other organic compounds accidentally finding their way into the bilge. The Navy is currently investigating ultrafiltration membranes to remove all of these and meeting with great success in laboratory and early shipboard testing (Tompkins 1997). The ceramic membranes currently being evaluated have a pore size of fifty angstroms. No particle larger than this can pass through them which effectively filters out most oil and other contaminants. Shipboard test results consistently average less than ten-ppm oil in the effluent regardless of influent oil concentration. When operational, use of this polishing system, downstream of an OWS, may preclude the need for an OCM. Membrane pore size will make it physically impossible for oil to be discharged in concentrations exceeding legal requirements. Figure 16 shows the laboratory membrane polisher under development at CDNSWC.

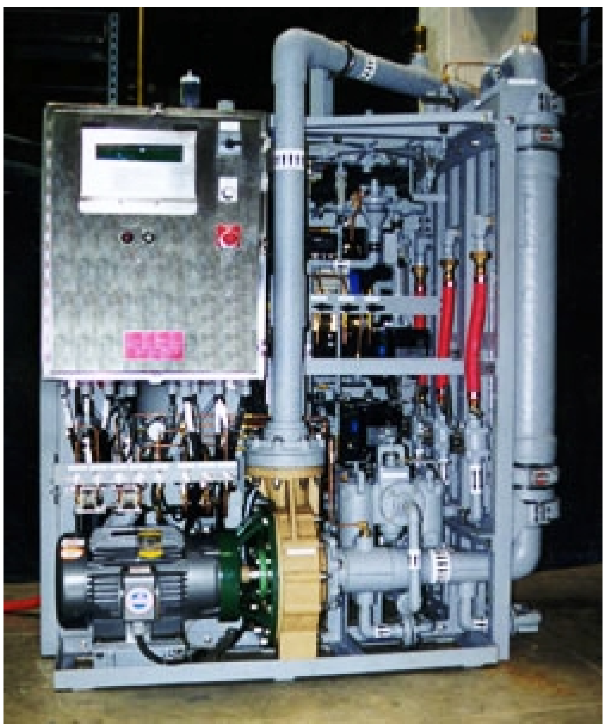

Figure 16. Oil Ultrafiltration Polishing Membrane

Another source of oily wastewater that the Navy is currently addressing is from compensated fuel ballast tank systems on many Navy ships. These systems use several partitioned fuel tanks that contain both water and fuel to correctly ballast the ship. As fuel is burned, water is added to the tanks to replace the lost volume and keep the ship within the specified stability parameters. The main drawback of this system is that a portion of this water, at the interface zone, becomes contaminated with fuel. When the ship is refueled, most of the water, including that that is fuel contaminated is displaced overboard. No existing separator is suited to processing this waste stream because refueling occurs at such a high rate. Therefore, the Navy is investigating modifications to the fuel tanks to minimize fuel/water mixing and eliminate water hideout as well as instituting new ballast water management practices to minimize the overboard discharge of fuel and contaminated water. The most effective way to prevent fuel spills from this source is to design ESW 21 as a clean ballast ship. Compensated fuel systems provide the advantage of reduced tankage, and reduced ship size resulting in reduced acquisition costs, but are prone to causing fuel spills. Clean or segregated ballast uses separate tanks for fuel and seawater ballast for ship stability. ESW 21 must trade off the acquisition cost advantage of compensated fuel ballast, with direct cleanup costs and political damage to the Navy associated with fuel oil spills.

Ozone Depleting Substances

Cessation of CFC and Halon production in the U.S. has resulted in a significant challenge for the Navy, which relies on these compounds extensively for daily ship operation. It has also resulted in a significant R&D program to find CFC free alternatives for shipboard use. A direct drop in replacement does not exist for the several key CFCs and Halons used by the Navy. This resulted in an evaluation of non-ozone depleting refrigerants and fire fighting compounds in existence and under development and an analysis of the Navy's systems and needs. The resulting program employed a multi-tiered approach that included conserving existing supplies of ODSs (principally through improved maintenance), converting systems to a non-ozone depleting substance where technically and economically feasible, and establishing a mission-critical reserve that would support the Fleet until individual systems are converted or retired.

The Navy's mission-critical reserve of CFCs and Halons (CFC-11, 12, and 114; and Halon 1211 and 1301) was established in 1994, it was determined by analyzing the consumption rates of Fleet refrigeration and fire fighting systems against the conversion and retirement schedule of systems and ships. A formal system has been developed to monitor the drawdown of these critical compounds. Current projections indicate a sufficient reserve of all compounds to meet anticipated Fleet requirements until 2050.

The Navy has over 1,000 air conditioning and refrigeration (AC&R) plants that use CFC-12. Hydrofluorocarbon 134a (HFC-134a) was selected as the replacement for CFC-12 as it is non-ozone depleting, has similar physical and thermodynamic properties, and is being marketed in the refrigeration industry as an alternative to CFC-12. However, the two compounds are not identical, resulting in an approximate refrigeration plant cooling loss of thirty-five percent and the need for an oil cooler. Conversely, reciprocating compressor air conditioning plants actually showed a minor increase in cooling performance. Both systems require an alternative compressor lubricant, as HFC-134a is not compatible with the mineral oils used in CFC-12 plants, an alternative dehydrator, and a leak detector. Refrigeration plants that cannot accept the thirty-five percent cooling loss require plant modifications to increase compressor size or speed. HFC-134a conversions began in 1992, and the Navy expects to convert over 980 plants by the year 2005. HFC-134a has also been selected as the refrigerant for the AC&R plants on all new ship designs. ESW 21 will likely use HFC-134a AC&R plants.

The Navy is one of the largest users of CFC-114 in ship and submarine air conditioning plants. Over 900 plants are installed on more than 250 surface combatants and submarines. Considerable work went into developing a substitute for CFC-114 as no suitable compound existed when the ODS Program began. In 1994, the Navy selected HFC-236fa as the backfit alternative for CFC-114 based on its zero ozone depleting potential, favorable laboratory test results, and a commitment from chemical companies that they would continue to produce the compound. HFC-236fa was thoroughly tested at CDNSWC, Annapolis Detachment, in all surface ship air conditioning plants. Submarine plants were not tested as the Chief of Naval Operations decided in August 1994 that submarines would retain their CFC-114 plants and draw from the mission-critical reserve. Testing revealed that new compressors were required for each plant to operate on the new refrigerant and York International was awarded a contract to help the Navy develop the prototype conversion kits. Successful laboratory testing with the redesigned compressors and conversion kits was followed by shipboard testing aboard USS *Normandy* (CG 60) in 1998. The Navy currently plans to install conversion kits in 583 plants by 2016 (Breslin 1997).

Halon 1301 is the Navy's premier fire fighting agent and unlike CFC-12 and CFC-114, a near substitute has not yet been found. Use of sulfur hexafluoride to test Halon shipboard fire fighting systems has significantly reduced Halon 1301 emissions. Unfortunately, sulfur hexafluoride is not an acceptable fire-fighting agent. Heptafluoropropane

(HFP) is closest to duplicating Halon 1301 performance and is ozone friendly but requires two to three times the space and weight as Halon 1301. That is not considered acceptable so Halon 1301 will continue to be used until a suitable substitute can be found and it will be supported by the mission-critical reserve. R&D efforts are ongoing to develop alternatives to Halon 1301, by investigating chemical compounds with no ozone depleting potential, and the effectiveness of water mist based fire-fighting systems. Halon 1211 will also be supported by the reserve until systems using it are retired.

Hazardous Material Management

Navy ships are large, floating, industrial complexes outfitted with an extensive array of electro-mechanical equipment, manufacturing and repair facilities, and ship protective systems. Many of which use or generate used or excess hazardous material in their everyday operation and maintenance. In fact, there are literally thousands of hazardous materials used in an equal number of maintenance and repair actions. Under the law, Navy ships are not regarded as hazardous waste generators and are not required to comply with federal laws regulating the generation, transfer and disposal of hazardous wastes. However, all Navy ships hold their excess/used hazardous material and offload it in port in accordance with statutory requirements. Navy facilities have been required to reduce their hazardous waste generation and disposal quantities by fifty percent from a 1994 baseline (Executive Order 12856). This presents a challenge when seventy percent of naval facility's hazardous waste originates on, and is offloaded from, Navy ships. Obviously, ships must reduce hazardous waste generation to allow the facility to meet its compliance goal.

The Hazardous Materials Control and Management and the P2 Afloat Programs have been developed to address these concerns. The former program seeks to identify and implement commercially available material and/or process substitutes for hazardous materials used aboard ships and submarines such as cleaning compounds and solvents, adhesives and sealants, and lubricants and greases. Combined with an established hazardous waste tracking and disposal system, this program has substantially reduced the quantity and nature of hazardous material used onboard and the ensuing shore disposal costs, $17M in fiscal year 1995 alone (NAVSEA November 1997).

Navy ships are being modernized to include a Hazardous Material Minimization Center (HAZMINCEN). This is a single, customer-friendly, shipboard facility that supports the issue, control, and reutilization of hazardous materials. The facility is usually managed by the ship's Supply Officer and is directly linked to the ship's inventory control point using the Consolidated Material Reutilization and Inventory Management Program (CHRIMP) and its associated computer based Hazardous Inventory Control System (HICS). Ergonomically laid out and proven successful in prototyping aboard USS *John Hancock* (DD 981), the HAZMINCEN provides centralized, efficient, and documented shipboard management of hazardous materials, offering inventory tracking, inventory reutilization, decreased transaction times, and reduced maintenance labor hours. ESW 21 design should incorporate a HAZMINCEN.

The P2 Afloat Program determines and implements hazardous material source reduction initiatives, process or equipment changes, and recycling or reuse programs onboard ships. This program began in 1995 when CDNSWC was tasked to investigate and find solutions for excess/used hazardous materials issued aboard Navy ships. To date, ten ships and two barges have been selected as prototype platforms where hazardous material records were reviewed and pollution prevention “opportunities” selected for evaluation onboard to reduce, reuse, or recycle the hazardous materials generated. The program has focused on the direct use or minimal reengineering of COTS equipment as the “opportunity” which is then evaluated aboard ship. Successful equipment that shows a positive return on investment within three years or less will be transitioned to the Fleet. The following equipment has proven successful, and is planned for Fleet transition by the year 2006: Large Aqueous Parts Washer, Top-Loading Aqueous Parts Washer, Pressure Washer, In-Drum Compactor, Cable Cleaner/Lubricator - High Viscosity, Cable Cleaner/Lubricator - Low Viscosity, Glycol Recycler, Electronic Particle Counter, Hydraulic Fluid Purifier, Maintenance-Free Battery, Mercury Ion Exchange Cartridge System, Electronic Component Cooler Gun, Paint Dispenser, HVLP Paint Gun System, Paint Gun Cleaning Station, Paint Brush Holder, Drum Level Indicator, Hand Pump/Spray Bottle Set, Hand Wipes Kit, Grease Management System, Rag Recycling System, Reciprocating Saw, Explosion Proof Vacuum, Pneumatic Backpack Vacuum, Pneumatic Sanding System, and Pneumatic Vacuum (Hays and Schuh 1998).

Paint and Preservation Systems

The Navy uses a variety of paints and coatings including epoxies, alkyds, vinyl's, and enamels to protect surfaces aboard ship. Current application and removal intervals are based on surface condition and ship availability to an industrial facility. Unfortunately, while the Navy is currently in compliance with all environmental regulations regarding paint application and removal, this one activity represents the single largest source of air pollution at Navy shipbuilding and repair activities. All paints authorized for use onboard Navy ships and in the Navy supply system meet current VOC standards. Future regulations will likely continue the mandate for reduced releases of volatile organic compounds (VOC) and hazardous air pollutants (HAP) during painting operations. This will require that Navy to develop lower VOC and HAP paints with greater wear characteristics or paint emission collection equipment/procedures and improved methodologies for determining when the paint or coating must be replaced or a combination of these. The Navy is currently investigating low VOC/high solids paints for shipboard application and these systems will likely be ready for use on ESW 21.

Underwater hull coating systems typically include a base anticorrosive coating covered by an antifouling coating. The antifouling topcoat inhibits the development of marine growth on the hull that is undesirable because it increases drag and fuel consumption, while decreasing vessel speed. Antifouling coatings are by definition harmful to marine life, heavy metals used to inhibit marine growth persist in the environment as they wear off of the ships' hull and accumulate in several species of marine life. Research is currently investigating coating systems that are benign once released into the environment. Significant work accomplished to date has replaced the use of tributyltin (TBT) in many applications with copper-based antifoulants. The antifouling coating systems applied varies depending upon hull material. Steel, fiberglass, glass reinforced plastic, and wood hulls are typically coated with copper-based coatings, and aluminum hulls with TBT or biocide-free silicon based coatings.

A new marine growth prevention system under development is based on "fouling release" rather than "anti-fouling." In these types of coating systems, fouling is allowed to grow and when the vessel moves through the water they release (slide off). Silicone based coatings are used which leave a slick surface as compared to the rough texture of copper anti-fouling coatings. Marine organisms are unable to form a chemical bond with the silicone, only suction type attachment. The force generated by the ship's movement through the water washes the organism off the hull. The speed required for release is related to the growth's cross sectional area. Current products show almost complete cleaning when the vessel reaches speeds of about eighteen knots. ESW 21 will likely be treated with copper based hull antifouling systems, until alternative systems are proven.

Engine Air Emissions

U.S. Navy ship engine emissions are not currently regulated, however this may change with adoptation of Annex VI or by EPA rule making. Regulations will likely only apply to diesel powered ships, with gas turbines excluded. Development of treatment systems and subsequent modernization of warships may be required in the future. Engine emissions can also be controlled by changing operational procedures to limit speeds when within regulated air sheds, movement of operation areas farther from the coast, and modification of engine timing (diesel) to reduce specific pollutant production. ESW 21 engine emissions will likely be regulated when operating within U.S. territorial waters and in some areas overseas.

Non-Indigenous Species

No non-indigenous specie has received the press of the zebra mussel. Accidentally introduced to Lake St. Clair in 1986 from the ballast water of a foreign ship, the small mollusk has taken over the entire Great Lakes region (with population densities exceeding 30,000 individuals/cubic-meters in some areas) and is spreading into nearby drainage's including the Mississippi River system (Dobes 1997). The zebra mussel, clogging fresh water system intakes and costing the water industry billions of dollars to remove and deal with and also threatening to collapse the entire Great Lakes ecosystem, is a stellar example of the problems non-indigenous species can cause. This single event focused world attention on ballast water as a vector for non-indigenous species introduction.

All large ships, including Navy vessels, use ballast water for stability, trim, and list control. Since 1994, it has been Navy policy to exchange (two times) any ballast water taken on "in polluted waters" or within three nm from land (a common occurrence for amphibious ships) with water located outside twelve nm from land. The Navy also washes sediment (which can also harbor non-indigenous species) off anchors and other equipment and cleans chain lockers to remove sediment. These procedures have proven effective for the Navy although the 1996 Noninvasive Species

Act may eventually require the Armed Services to develop ballast water management practices appropriate to their vessels (Dobes 1997). MARPOL Annex VII, which is currently under development and addresses ballast water management, may also have an impact on future ship operations and designs.

FUTURE VISION

The strategy for realizing the ESW 21 begins with a rigorous systems analysis of the processes and procedures that must be incorporated to meet the ESW 21 operational requirement over the thirty to fifty year ship life cycle. Whole ship considerations in the design and construction, with regard for reduced total ownership cost must be given high priority. One of the most difficult principles to quantify is the cost of environmental compliance and cost avoidance. ESW 21 designers must make best available estimates for future environmental cost avoidance (i.e. projected cost savings from reduced oil spill cleanup costs or waste management) and incorporate them into their return-on-investment calculations. A difficult task, but one that offers the Program Manager with large potential savings in operational costs that must be incorporated into programmatic decision making.

Figure 17 provides a strategy for achieving the ESW 21. Pollution Prevention must be a guiding principle, minimization of waste streams through source reduction, minimal dependence on paper products, and design in reuse and recycling systems. Development of a life cycle Hazardous Material Minimization Plan to provide a map and inventory of shipboard HAZMAT, and effective reduction in HAZMAT necessary for operation and maintenance is required. Integration of waste stream management processes and simplification of these systems to achieve virtual automatic operation is essential. Most of the various technologies to achieve the integrated waste management vision have been demonstrated in the laboratory, some have yet to be.

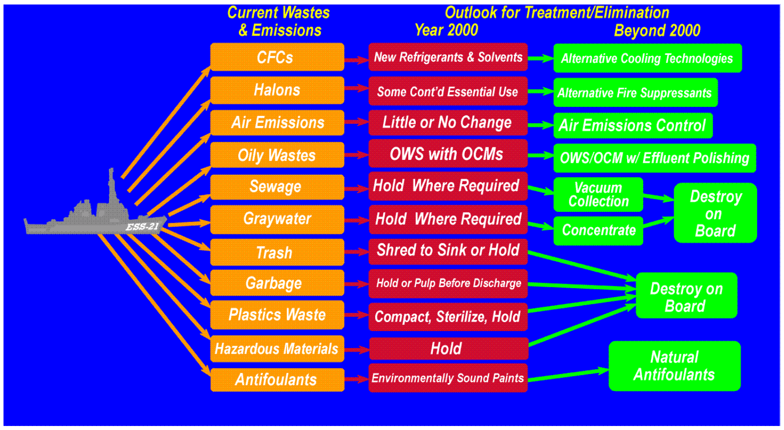

Figure 17. Strategy for Environmentally Sound Ships

Figure 18 provides a diagram of the Integrated Liquid Discharge System (ILDS). This system combines sewage, graywater and oily wastewater into a common "flow through" treatment system. Oily wastewater is first treated with an OWS (Figure 15), effluent is then polished to ten ppm or better in a ceramic ultrafiltration membrane unit (Figure 16) before overboard discharge, and the concentrate is directed to a thermal destruction device. Sewage to be collected via a VCHT system, processed in a flow through Marine Sanitation Device (MSD) using membrane technology with effluent directed overboard following disinfection, and concentrate (sludge) consumed in the thermal destructor. Graywater to be concentrated in a bio-membrane system (Figure 14) to meet effluent discharge standards, and the concentrate is destroyed in the thermal destructor. The Advanced Vortex Incinerator (Figure 13) offers great potential and promise as the ILDS thermal destruction device.

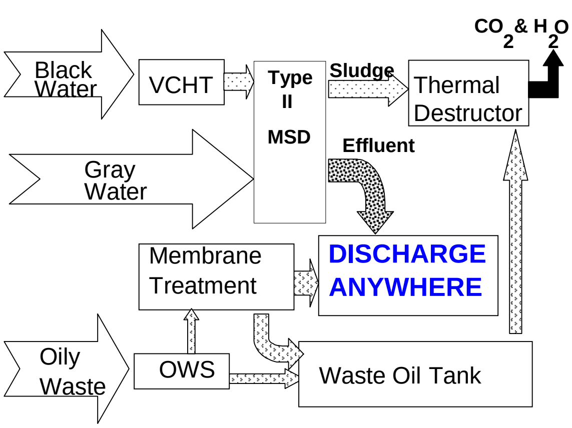

Figure 18. Integrated Liquid Discharge System Concept

Source reduction plays a large role in reducing the amount of packaging on supplies that ultimately ends up as waste. This strategy will be expanded in the future not just to supplies but to other waste generating activities as well. Standard shipping containers will be developed to transport supplies back and forth between ships with a much longer life than the standard Navy tri-wall. A family of standardized and reusable parts containers will be developed. Submarine-like load out procedures must be adopted where most packing material is left behind on the pier. Information and newsletters distributed electronically will significantly reduce paper generation and waste. Hand dryers versus paper towels in crew heads will accomplish the same thing. These are but a few of the ideas being pursued by NAVSUP and NAVSEA to minimize the quantity of waste generated. The Smart Ship Program, which is developing technologies to reduce future ship manning, has more potential to reduce the quantity of waste generated than any other program because most solid waste generation is a simple function of the number of people onboard. Reduced personnel means less waste and storage volume to hold it or a smaller system to process it.

Alternatives for management of the solid waste stream can be broken down into two basic methods: hold for shore based disposal, or discharge it overboard. Technology can be used to process it into a benign state for overboard discharge or reduce the volume for onboard storage. A survey of advanced thermal destruction technologies by CDNSWC found that the most promising for warship application is plasma arc pyrolysis. CDNSWC developed a design for a shipboard Plasma Arc Waste Destruction System (PAWDS) in 1995, and it is currently being evaluated as an Advanced Technology Demonstration (ATD) that commenced in 1998. The ATD is a three-year program that will build and test PAWDS on land to determine its feasibility for advanced development and eventual Navy shipboard use. Risks include: size, weight, waste processing throughput, power and cooling requirements, complexity and cost constraints. In this system, waste is preprocessed to reduce material size and homogenize it, wastes are then introduced into an extremely high temperature zone (10,000 degrees Celsius) produced by a plasma arc torch in the absence of air. The resulting reaction splits the organic waste into individual gaseous molecules that are oxidized into carbon dioxide and water vapor in a secondary chamber; inorganic wastes are melted into slag and tapped off to a mold. The carbon dioxide and water vapor are released to the atmosphere and the greatly reduced volume slag billet is held onboard. PAWDS development will first concentrate on destruction of organic solid waste (including plastics), then on concentrated liquid waste, and finally solid inorganic wastes. Energy requirements for liquid waste management are seen as one of the greatest challenges that must be overcome to achieving necessary waste throughput for all waste streams. The feasibility and practicality of inorganic solid waste processing is also being evaluated, the cost-benefit of reduction of various solid materials into a homogeneous mixture of glassified slag must be determined. PAWDS operating temperatures are sufficient to process HAZMAT, medical and dental waste as well as material classified as dunnage (textiles, rope, wood). A concept for this system is provided as Figure 19.

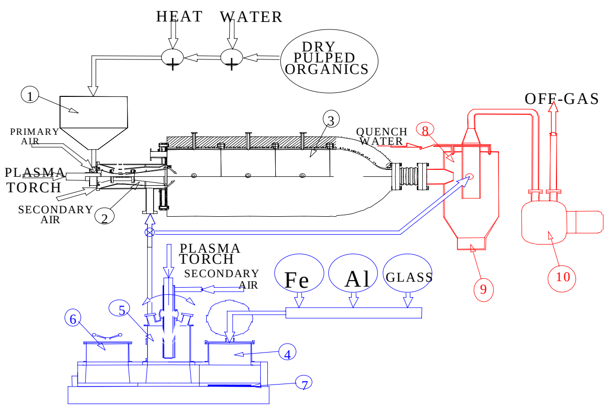

Figure 19. Plasma Arc Waste Destruction System Concept

Table 9: PAWDS Key

1	Feed Hopper
2	Eductor – Gasifier
3	Secondary Combustion Chamber
4	Loading Station
5	Melting/Oxidation Station
6	Cooling Station
7	Demolding Station
8	Water Quench
9	Particle Removal
10	Liquid Ring Pump

As illustrated in Figure 19, PAWDS has four distinct processing zones. In the first zone dry pulped organics are introduced into the Plasma Torch Eductor where initial pyrolysis occurs. In the Secondary Chamber complete oxidation of organic material into carbon dioxide and water vapor occurs. The third zone contains a gas management system that removes residual inorganic material (such as heavy metals) that may have entered with organics, and manages the inorganic zone vent system gases. The gas management system prevents release of harmful materials into the atmosphere. The fourth zone uses a second plasma torch to reduce inorganic material to slag.

Development of PAWDS necessitates fostering partnerships with commercial industry. Leveraging the resources of government and private industry could result in a smaller and lighter marine incinerator or a PAWDS suitable for Navy and commercial ship (cruise line) use.

Source reduction and smaller crew sizes combined with continuing improvements in thermal destruction technologies places the Navy of the future in a position to process their waste in an environmentally acceptable manner. Reduced waste generation also makes storage more feasible although risks due to fire safety, health, and morale issues make this approach less favorable; it also leaves the ship dependent on waste reception facilities. An integrated waste management approach with centralized processing equipment feeding an advanced thermal destruction system will lower manpower requirements and minimize ship impact. This is the preferred approach for the ESW 21. Such a system, properly designed, could process most of the shipboard waste streams including solid waste, sewage, graywater, and bilgewater as well as hazardous and medical wastes. Figure 20 illustrates the conceptual Navy Integrated Waste Management System (NIWMS) processes that combines ILDS with PAWDS.

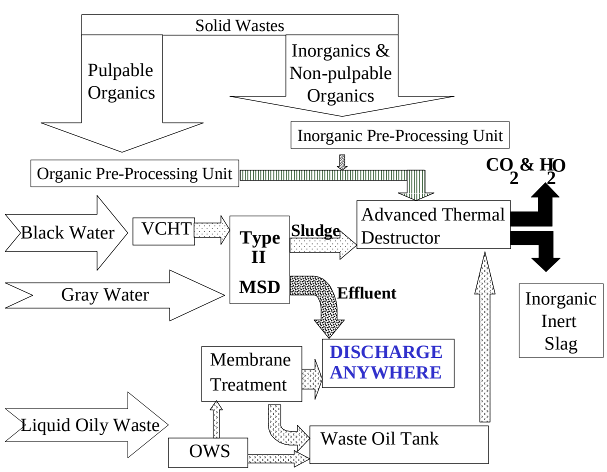

Figure 20. Navy Integrated Waste Management System Concept

CONCLUSIONS

In response to U.S. Law, the Navy has implemented changes in operational procedures, educated its personnel, institutionalized pollution prevention, and developed and fielded waste management equipment to enable environmental compliance. The U.S. Navy today is designing and building new classes of ships for the 21^{st} Century and beyond. These ships will be characterized by dramatically reduced manning from today's levels and will be designed to comply with expected environmental regulations. These designs will benefit from extensive pollution prevention measures to reduce the waste stream managed by pollution control equipment. Total Ownership Cost incorporating shore support and ship life cycle costs together with risk assessments will govern technology decisions made by Navy Program Managers. To be considered, alternatives must show an overall return on investment as compared to existing technologies, have a manageable level of risk and be affordable. To achieve the ESW 21, life cycle costs of alternatives must be evaluated, and support given to choosing the best value alternative over the thirty to fifty year life cycle of the ship.

ESW 21 must be designed from the onset to be compatible with the environment as defined by existing and foreseeable regulations. The responsibility rests with each functional area to consider environmental protection in performing their engineering design work. Materials should be selected based in part on their durability, longer durability translating into reduced maintenance interval resulting in less waste produced, cost savings financially and to the environment. Structural designers should consider fuel and ballast tank designs that minimize turbulent flow to minimize fuel and water mixing if compensated fuel systems are required, ballast tanks should minimize undrained pockets that harbor sediment and associated non-indigenous species. Structural members should be designed to maximize coating performance (rounded edges/bulbous design provide better coating performance), increased cost to fabricate should be compared to decreased preservation frequency and subsequent cost savings. Hull and deck machinery should be selected and integrated into the ship to minimize fluid leakage overboard, and exposure to the elements resulting in more frequent maintenance. Logisticians should work with naval architects to develop reusable logistics modules to reduce generation of packaging waste and enhance stores loading. Almost every ship design decision has an operations and support implication with associated environmental cost. Each discipline involved in the ship design is responsible for establishing the degree to which ESW 21 fulfills its environmental mission.

Future Navy waste stream management systems will be integrated and be operated by a fraction of the personnel required today. System designs must evolve from today's stand-alone philosophy to one of integrated processing. Incorporation of advanced control technology and materials is essential to minimizing manpower requirement for both operation and maintenance. These systems must also be simple to operate and maintain, compatible with new strategies that shift the majority of required maintenance to the shore establishment – minimizing maintenance required at sea. Figure 21 illustrates the evolution in technology that will enable ESW 21.

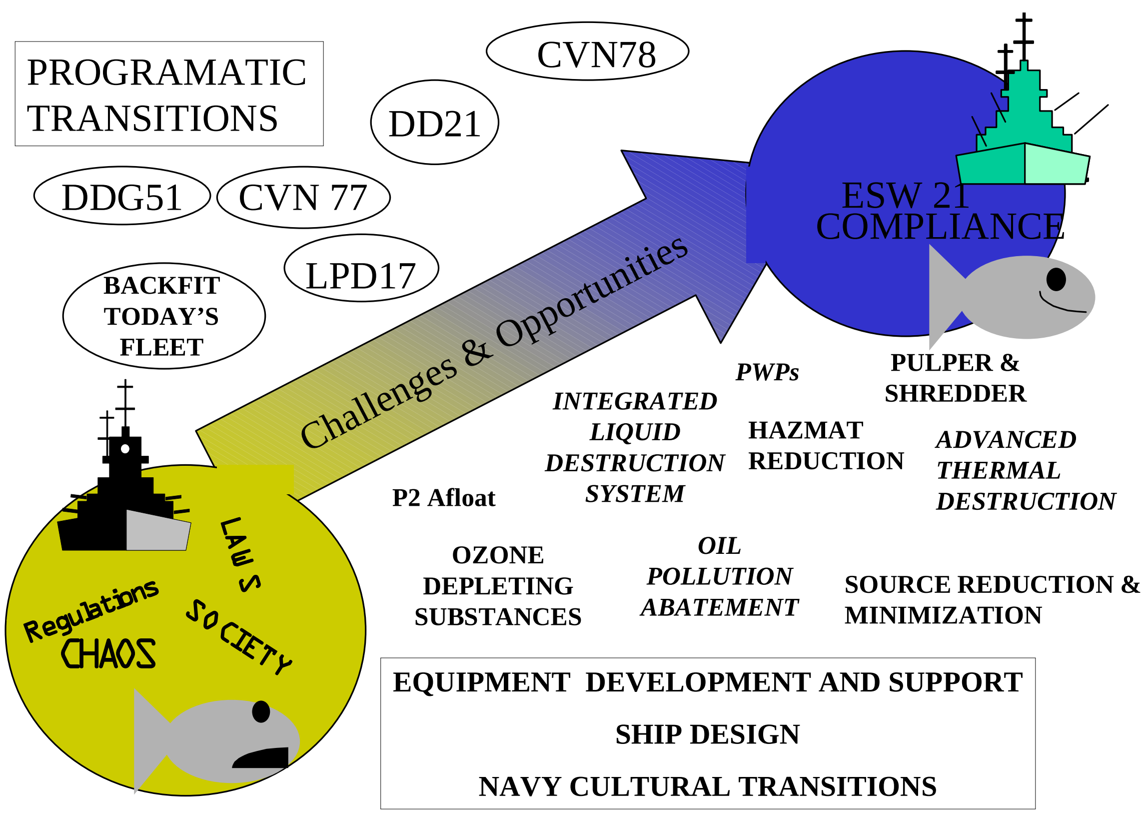

Figure 21. Chaos to Compliance, The Fleet of Yesterday to the Fleet of Tomorrow

Advanced thermal destruction devices offer the best technology solution for managing the ESW 21 waste stream. NIWMS may provide the all purpose solution, but transition to this system will involve a staged approach as components are developed. ILDS components are being perfected in commercial sector and Navy labs. PAWDS, when successfully developed, offers the greatest potential benefit as the key element in the NIWMS. Development of these systems has equal potential value to the commercial marine industry and to foreign navies. For this reason, partnering between these groups must be pursued. With the risks and burden of development equally shared, there is tremendous potential payoff for all participants. After all, ESW 21 is in response to the mandate for environmental compliance, together the goal of these regulations can be realized, Figure 22.

Figure 22. The Bottom Line…

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Mr. Larry Koss (CNO N452) for Navy environmental leadership, stewardship, and genesis of the environmentally sound ship of the 21st century concept. Furthermore, the authors wish also acknowledge the contribution of those who persevered to create the reality of the Environmentally Sound Warship of the 21st Century including: Dr. Frank Ventriglio (NAVSEA 03V), Mr. Art Smookler (NAVSEA 03R - retired), Mr. Joel Krinsky (NAVSEA 03L), Mr. Anthony Nickens, Mr. Carl Adema and Mr. Anthony Rodriguez

(NAVSEA 03R), and Mr. Craig Alig (CDNSWC 63). It is through their combined efforts that the Navy has brought the vision of an Environmentally Sound Warship for the 21st Century closer to reality.

This paper was developed in conjunction with the Society of Naval Architects and Marine Engineers paper “The U.S. Navy Solid Waste Management Challenge” presented at the 1999 Joint California Sections meeting.

The views expressed herein are the personal views of the authors and are not necessarily the official views of the Department of Defense nor the Naval Sea Systems Command. Reference to a particular vendor or product is not intended as endorsement to either the vendor or the product.

REFERENCES

Act to Prevent from Pollution from Ships, 33 U.S.C. Sections 1901 through 1912.

Breslin, D.A., G.P. Brunner and J.C. Thill, “Navy’s CFC & Halon Elimination Program,” Proceedings of the ASNE Environmental Symposium "Environmental Stewardship: Ships and Shorelines," November 1997.

Clean Air Act, 42 U.S.C. Sections 7401 to 7642.

Demboski, D.A., J.H. Benson, G.E. Rossi, N.S. Lewitt and M.A. Mull, “Evolutions in U.S. Navy Shipboard Sewage and Graywater Programs,” Proceedings of the ASNE Environmental Symposium "Environmental Stewardship: Ships and Shorelines," November 1997.

Dobes, J.C., “Ballast Water Management – A Glimpse of the Future,” Proceedings of the ASNE Environmental Symposium "Environmental Stewardship: Ships and Shorelines," November 1997.

Federal Water Pollution Control Act, 33 U.S.C. Sections 1251 to 1387.

Executive Order 12856, "Federal Compliance with Right-to-Know Laws and Pollution Prevention Requirements," August 3, 1993.

Hays, R.E. and R. Schuh, "Pollution Prevention Opportunities in Shipboard Operations," Proceedings of the Third Annual Joint Service Pollution Prevention Conference and Exhibition, August 1998.

International Maritime Organization, "International Convention for the Prevention of Pollution from Ships," (MARPOL 73/78).

Marine Mammal Protection Act of 1972, 16 U.S.C. Sections 1361 to 1421h.

Marine Protection, Research and Sanctuaries Act of 1972, 33 U.S.C. Sections 1401 to 1445.

Markle, S.P. and A.J. Brown, "Naval Ship Engine Exhaust Emission Characterization," Naval Engineers Journal, September 1996.

Markle, S. P., S.E. Gill and P.S. McGraw, "The U.S. Navy Afloat Solid Waste Management Challenge," Society of Naval Architects and Marine Engineers Joint California Sections Meeting, May 1999.

Markle, S.P., and S.E. Gill, "CVN 68 Class Solid Waste Flow Analysis," ASNE Naval Engineers Journal, November 1998.

Military Specification, MIL-I-15650E, "Incinerators, Shipboard Use," January 1991.

Military Specification (Navy), MIL-S-901D (NAVY), "Shock Tests H. I. (High-Impact) Shipboard Machinery, Equipment, and Systems, Requirements For," 17 March 1989.

Military Standard, MIL-STD-167/1, "Type 1 Mechanical Vibrations of Shipboard Equipment," 1 May 1974.

Mull, M., A.D. Nickens and M. Redmond, “Design Considerations for an Environmentally Friendly Sound Warship,” Society of Naval Architects and Marine Engineers Transactions, Volume 106, Spring 1999.

National Defense Authorization Act for Fiscal Year 1994.

Naval Sea Systems Command (SEA 03L), “Report of the Fleetwide Environmental Survey,” June 1997.

Naval Sea Systems Command (SEA 03R16), “Navy Surface Ship Waste Management & Disposal Costs,” November 1997.

Naval Sea Systems Command (SEA 03V), “U. S. Navy Shipboard Solid and Plastics Waste Management Program Plan,” April 1993.

Naval Surface Warfare Center – Carderock Division, “Shipboard Solid Waste Management Equipment Guide,” NSWCCD-TR-63-97/25, September 1997.

Navy Inventory Control Point (NAVICP), “The Navy Wraps Up SEA Trash - A Vendor’s Guide to the Navy’s Waste Reduction Program,” 1997.

Nickens, A.D., et al “ Environmental Compliance: Requirements and Technology Opportunities for Future Ships,” Naval Engineers Journal, May 1997.

Public Law 100-220, Marine Plastic Pollution Research and Control Act, 1987.

Public Law 104-201, National Defense Authorization Act for Fiscal Year 1997, section 324.

SEIC - Shipboard Environmental Information Clearinghouse Internet Website, http://navyseic.com.

Solid Waste Disposal Act, 42 U.S.C. Sections 6901 to 6992k.

Tompkins, K.T., L.P. Murphy, B.L. Owsenek, R.P. Pignataro, and A.T. Rodriguez, “Ultrafiltration Membrane Polishing System for Shipboard Treatment of Oily Wastewater,” Proceedings of the Environmental Symposium "Environmental Stewardship: Ships and Shorelines," November 1997.

Toxic Substances Control Act, 15 U.S.C. Sections 2601 to 2692.

U.S. Chief of Naval Operations Instruction 5090.1 Series, “Environmental and Natural Resources Program Manual,” February 1998.

U.S. Department of Defense Regulation 5000-2.R, “Mandatory Procedures for Major Defense Acquisition Programs (MDAPS) and Major Automated Information Systems (MAIS) Acquisition Programs,” 6 October 1997.

U.S. Department of the Navy, “Final Environmental Impact Statement: Disposal of U.S. Navy Shipboard Solid Waste,” August 1996.

U.S. Department of the Navy, “Report to Congress: U.S. Navy Ship Solid Waste Management Plan for MARPOL Annex V Special Areas,” November 1996.

U.S. Environmental Protection Agency, Proposed Rules for “Control of Emissions of Air Pollution from CI Marine Engines at or above 37 kW,” 40 CFR Part 94, Federal Register Vol. 63, No. 238, December 11, 1998.

U.S. Environmental Protection Agency and U.S. Department of Defense, Proposed Rules for “Uniform National Discharge Standards for Vessels of the Armed Forces,” 40 CFR Chapter VII Part 1700, Federal Register Vol. 63, No. 167, August 25, 1998.

U.S. Environmental Protection Agency, Final Rule "Accelerated Phaseout of Class I ODS," 58 FR 65018, December 10, 1993.

ABBREVIATIONS/DEFINITIONS

AC&R	-	Air Conditioning and Refrigeration
AEP	-	Afloat Environmental Protection
AEPC	-	Afloat Environmental Protection Coordinator
APPS	-	Act to Prevent Pollution from Ships
ATD	-	Advanced Technology Demonstrator
BOD_5	-	Biological Oxygen Demand
CAA	-	Clean Air Act
CDNSWC	-	Carderock Division, Naval Surface Warfare Center
CFC	-	Chlorofluorocarbon
CFR	-	Code of Federal Regulations
CHT	-	Collection, Holding and Transfer
CLCU	-	Closed Loop Cooling Unit
CMU	-	Compress Melt Unit
CNO	-	Chief of Naval Operations
COTS	-	Commercial Off the Shelf
CPS	-	Collective Protection System
CWA	-	Clean Water Act
DoD	-	Department of Defense
EIS	-	Environmental Impact Statement
EMI	-	Electromagnetic Interference
EPA	-	United States Environmental Protection Agency
ESW 21	-	Environmentally Sound Warship for the 21st Century
gpd	-	gallons-per-day

gpm	-	gallons-per-minute
HAP	-	Hazardous Air Pollutant
HAZMINCEN	-	Hazardous Material Minimization Center
HAZMAT	-	Hazardous Material
HFC	-	Hydrofluorocarbon
HVAC	-	Heating, Ventilation and Air Conditioning
ICBT	-	Interactive Computer Based Training
ILDS	-	Integrated Liquid Discharge System
kW	-	kilowatt
lb/hr	-	pound-force per hour
lb/per-day	-	pound-force per person per day
LP	-	Large Pulper
M	-	Million
MARPOL 73/78	-	International Convention for the Prevention of Pollution from Ships
MGS	-	Metal Glass Shredder
MPCD	-	Marine Pollution Control Device
MLDT	-	Mean Logistics Delay Time
MTBF	-	Mean Time Between Failures
MTBCF	-	Mean Time Between Critical Failures
MSD	-	Marine Sanitation Device
MTTR	-	Mean Time to Repair
NAAQS	-	National Ambient Air Quality Standards
NAVICP	-	Navy Inventory Control Point
NAVSEA	-	Naval Sea Systems Command
NAVSUP	-	Naval Supply Systems Command
NDAA	-	National Defense Authorization Act
NEPA	-	National Environmental Policy Act
NIWMS	-	Navy Integrated Waste Management System

nm	-	Nautical Mile
NO_X	-	Oxides of Nitrogen
OBB	-	Odor Barrier Bag
OCM	-	Oil Content Monitor
ODS	-	Ozone Depleting Substance
OPNAV	-	Office of the Chief of Naval Operations
ORD	-	Operational Requirements Document
OWS	-	Oil Water Separator
P2	-	Pollution Prevention
PAWDS	-	Plasma Arc Waste Disposal System
PCBs	-	Polychlorinated Biphenyls
ppm	-	parts-per-million
PRIME	-	Plastic Removal in the Marine Environment
PWP	-	Plastic Waste Processor
RCRA	-	Resource Conservation and Recovery Act
SEIC	-	Shipboard Environmental Information Clearinghouse
SO_X	-	Oxides of Sulfur
SP	-	Small Pulper
SWS	-	Solid Waste Shredder
TBT	-	Tributyl Tin
TOC	-	Total Ownership Cost
TSCA	-	Toxic Substance Control Act
TSS	-	Total Suspended Solid
UNDS	-	Uniform National Discharge Standards
U.S.	-	United States
U.S.C.	-	United States Code
VCHT	-	Vacuum Collection, Holding and Transfer
VOC	-	Volatile Organic Compound

WRAPS	-	Waste Reduction Afloat Protects the Sea